U. S. DEPARTMENT OF AGRICULTURE
OFFICE OF EXPERIMENT STATIONS

Agricultural Investigations at Rothamsted, England

DURING A PERIOD OF FIFTY YEARS

SIX LECTURES DELIVERED UNDER THE PROVISIONS OF

THE LAWES AGRICULTURAL TRUST

BY

SIR JOSEPH HENRY GILBERT, M. A., LL. D., F. R. S., etc.

UNDER THE AUSPICES OF THE ASSOCIATION OF AMERICAN AGRICULTURAL COLLEGES AND EXPERIMENT STATIONS. IN NOVEMBER, 1893

WASHINGTON
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LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., October 15, 1894.

Sir: I have the honor to transmit herewith for publication as Bulletin No. 22 of this Office six lectures on the agricultural investigations at Rothamsted, England, during a period of fifty years, delivered under the provisions of the Lawes Agricultural Trust by Sir J. Henry Gilbert, M. A., LL. D., F. R. S., etc., under the auspices of the Association of American Agricultural Colleges and Experiment Stations at Massachusetts Agricultural College, Amherst, Mass., November, 1893. It was the original intention to have these lectures delivered at Chicago before the convention of the Association of Colleges and Stations held in connection with the Agricultural Congresses of the World's Columbian Exposition, and the introductory lecture was actually so delivered by its distinguished author in October of last year. The crowded programme of the congresses and the distractions of the great fair prevented the completion of this plan, but the lectures were afterwards delivered before the faculty and students of the Massachusetts Agricultural College. The results of some work done in 1894 have since been incorporated in this bulletin.

It is deemed a peculiarly happy circumstance that after fifty years of continuous service in the cause of agricultural science one of the two men whose harmonious labors at Rothamsted during so long a period have made a remarkable and lasting impress on the agriculture of the world should be able to stand on the spot where the new world had gathered together in material form a magnificent epitome of human progress and tell to a delighted audience of American and foreign workers in kindred lines what had been accomplished by half a century of persistent and intelligent effort to advance our knowledge of the facts and principles on which progress in agriculture must proceed. The occasion would have been doubly interesting had Sir J. B. Lawes been able to accompany his lifetime coadjutor and friend, but he must have had great satisfaction in the reflection that the history of Rothamsted Experimental Station was to be told at such a time by a spokesman who had its interests equally at heart with himself.

Joseph Henry Gilbert was born at Hull August 1, 1817. His father was the late Rev. Joseph Gilbert, and his mother was well known as

an authoress, as Ann Taylor, of Ongar. After his school education he commenced his college courses at the University of Glasgow, where, as elsewhere, he devoted special attention to chemistry, working in the laboratory of the late Prof. Thomas Thomson. He next studied at University College, London, attending the classes of Professor Graham and others, and working in the laboratory of the late Dr. Anthony Todd Thomson, then the professor of materia medica, therapeutics, and toxicology. A short time was then spent in the laboratory of Professor Liebig, at Giessen, where he took the degree of doctor of philosophy. Returning to University College, London, Dr. Gilbert acted as class and laboratory assistant to Prof. A. T. Thomson in the winter and summer sessions of 1840–41, attending other courses at the college at the same time. He next devoted some time to the chemistry of calico printing, dyeing, etc., in the neighborhood of Manchester.

In 1843 Dr. Gilbert became associated with Mr. (now Sir) J. B. Lawes, of Rothamsted, Hertfordshire, and from that time he has continued to be engaged with him in a systematic series of researches on agricultural chemistry and physiology. The results of their investigations have been published in a series of papers, now numbering more than one hundred, in various journals, among which may be mentioned "The transactions and proceedings of the Royal Society," "The journal of the Royal Agricultural Society of England," "The journal of the Chemical Society," "The reports of the British Association for the Advancement of Science," "The journal of the Statistical Society, of the Society of Arts," etc., also in some official reports and elsewhere.

Dr. Gilbert was elected a member of the Chemical Society in 1841, the year of its formation; and he contributed to the first volume of its Memoirs a translation from the original German of a paper on the atomic weight of carbon by Professors Redtenbacher and Liebig. He was president of the society in 1882–83. He was elected a fellow of the Royal Society in 1860; and in 1867 the council of the society awarded to him, in conjunction with Mr. Lawes, one of the royal medals. He is also fellow of the Linnean Society and of the Royal Meteorological Society.

In 1880 he was president of the chemical section of the British Association for the Advancement of Science. In 1882 and 1884 he visited Canada and the United States, traveling over wide areas to study the conditions of the agriculture of those countries. In 1884 he was appointed Sibthorpian professor of rural economy in the University of Oxford, and he was reappointed for a second period of three years in 1887. He has held the directorship of the Rothamsted Laboratory since 1843.

Eighteen hundred and ninety-three was the jubilee year of the Rothamsted investigation, Sir J. B. Lawes and Dr. Gilbert having then worked together for fifty years. There was a jubilee celebration held at Rothamsted on July 29, 1893, which was presided over by the Right

Honorable Herbert Gardner, M. P., the minister of agriculture, when numerous addresses were presented to Sir John Lawes and Dr. Gilbert; among others, from the subscribers to the Jubilee Fund, bearing the signature of the Prince of Wales; from the Royal Agricultural Society of England, signed by the president, the Duke of Devonshire; from the Royal Society, from the Chemical Society, and from the Linnean Society, signed by their respective presidents; from the Royal Agricultural College, Cirencester; some from France, and one from the Association of Agricultural Chemists of Germany. A portrait of Sir John Lawes, by Herkomer, was also presented to him, and a piece of plate to Dr. Gilbert.

On August 11, 1893, Dr. Gilbert received the honor of knighthood. In September, 1893, the Liebig silver medal was awarded to Sir John Lawes and Sir Henry Gilbert by the curators of the Liebig Foundation of the Royal Bavarian Academy of Sciences at Munich. In the same year the president and council of the Society of Arts awarded the Albert gold medal both to Sir John Lawes and to Sir Henry Gilbert.

Sir Henry Gilbert received the honorary degree of M. A. at Oxford in 1884, that of LL. D. at Glasgow in 1883, and at Edinburgh in 1890; also that of Sc. D. at Cambridge on the occasion of the meeting there of the Royal Agricultural Society in June, 1894. He is life governor of University College, London; honorary member of the Royal Agricultural Society of England, of the Chemico-Agricultural Society of Ulster, of the Academy of Agriculture and Forestry of Petrovskoie, and of the Royal Agricultural Society of Hannover; foreign member of the Royal Agricultural Academy of Sweden; and corresponding member of the Institute of France (Academy of Sciences), of the Society of Agriculturists of France, of the Society for the Encouragement of National Industry, Paris, and of the Institut Agronomique of Gorigoretsk. He is also chevalier du mérite agricole (France), and (in conjunction with Sir J. B. Lawes) gold medalist of merit for agriculture (Germany).

In transmitting the manuscript of these lectures to the Secretary of Agriculture, with a request for their publication by this Department, Maj. H. E. Alvord, chairman of the executive committee of the Association of American Agricultural Colleges and Experiment Stations, well states the character of this publication in the following words: "The lectures comprise the only condensed, carefully prepared, and authorized review of the famous investigations by Lawes and Gilbert for half a century at Rothamsted. They constitute an extremely valuable and truly unique contribution to the literature of experimental agriculture." Much material hitherto unpublished in any form has been incorporated in this bulletin. For the information of some who may read these lectures it may be well to add that this is the second biennial course delivered in the country under the provisions of the Lawes Agricultural Trust. The first course, delivered at Washington,

D. C., August, 1891, by Robert Warington, F. R. S., was published as Bulletin No. 8 of this Office, and is now out of print, an edition of 5,000 copies having been distributed. In addition to these courses of lectures Sir J. B. Lawes has distributed to experiment stations in this country 26 complete sets of published papers on Rothamsted investigations, prepared at large cost, and expects to give us as many more. He has also sent to experiment-station workers and boards of control 800 copies of the outline "Memoranda" of these investigations.

Respectfully,

A. C. TRUE, *Director.*

HON. CHAS. W. DABNEY, Jr.,
Acting Secretary of Agriculture.

AGRICULTURAL INVESTIGATIONS AT ROTHAMSTED, ENGLAND.

INTRODUCTION.[1]

As you are doubtless aware, it is under the auspices of the Lawes Agricultural Trust, which provides for the periodical delivery in the United States of a course of lectures on the Rothamsted Investigations, that I appear before you to-day. Had the occasion been an ordinary one it would not be expected that at the age of 76 I should undertake the risks of so long a journey and the responsibility of delivering a course of lectures in this country. But the occasion is not an ordinary one. Thus the more systematic experiments at Rothamsted were commenced in 1843, so that the present year, 1893, is the fiftieth of their continuance, and it was considered desirable that under these circumstances something in the way of a general review of the half century's work and results should be given. Obviously, the execution of such a task could only be appropriately undertaken either by Sir John Lawes or by myself, who alone have worked together from the commencement to the conclusion of the fifty years. Sir John Lawes is, however, even more heavily handicapped by age than I am myself, and at the desire both of Sir John and of the trust committee I have accepted the responsibility.

I need not go into much detail as to the origin, scope, and plan of the Rothamsted Investigations. A good deal of information on the subject will be found in the early pages of the now annually issued Memoranda of the Origin, Plan, and Results of the Field and other Experiments conducted on the Farm and in the Laboratory at Rothamsted, and Mr. Warington considered it pretty fully in his first lecture in 1891.

I am sure you will readily understand that it is no easy task to compress within the limits of half a dozen lectures anything like an adequate account of the labors of a gradually increasing staff of workers over a period of fifty years. This must be fully recognized when it is borne in mind that the reports and other papers on the results at present number about 120, and that they occupy nearly 4,000 octavo and more than 800 quarto pages. These publications, moreover, brought

[1]This "Introduction" was also read at the meeting of the Association of American Agricultural Colleges and Experiment Stations, and of the Agricultural Congress at Chicago on October 17, 1893.

together as they have been into bound volumes for the purpose of distribution in a collective form, make up 6 octavos and 3 quartos; while papers since published are accumulating toward another volume. A few years ago 50 sets of the 9 volumes were prepared, requiring the reprinting of nearly 500 octavo pages and the purchase of a good deal of the quarto matter. As many of you are aware, a number of these complete sets of 9 volumes each—I believe 26 sets in all—were presented by Sir John Lawes to as many educational and experimental institutions in the United States; and I am authorized by Sir John to say that he hopes to be able to send perhaps about an equal number more sometime next year (1894). In all, 125 sets, involving the setting up of 1,100 pages octavo and about 370 pages quarto, are now in course of preparation. Of these our own board of agriculture takes 50, to distribute to various institutions in the United Kingdom. There will then be left only 75 sets for distribution by Sir John Lawes himself to our colonies and to foreign countries, including those still to be sent to the United States. It may be added that to provide any more sets than those now in preparation would necessitate further reprinting, almost in proportion to the number required; and when it is considered how much time must be expended in the revision of the reprints and how great the cost little surprise can be felt at the delay in the completion of the work and the necessary limitation of the number to be provided.

Unfortunately, however, besides all the published matter, there still remain large arrears of as yet unpublished results. It is from this mass of material, published and unpublished, that I have to make my selection in endeavoring to give such a view of the objects and results of the Rothamsted investigations as may be of value, both as illustrating the advance in knowledge already attained and as indicating points for future inquiry.

Obviously, the scheme proposed precludes the idea of going into much detail on any one subject, and supposes rather a comprehensive but at the same time only outline view of the whole. The next question is whether the illustrations relied upon should have reference primarily to results obtained in the field and in the feeding shed or chiefly to those of laboratory investigations. Now, as a prominent characteristic of the Rothamsted work has certainly been the devotion of great attention to both field and feeding experiments, and as by far the greater part of the laboratory investigations, whether chemical or botanical, have had for their object the solution of problems suggested by the field and feeding results, it has been thought that the most appropriate, and at the same time the most useful, course will be to give a comprehensive view of the plan and results of the field and feeding experiments themselves and to enforce the lessons which they teach by such reference to laboratory results as the questions raised require for their elucidation and as space and time will permit. In other words, the

analytical and other laboratory work must be treated as essential means to an important end, and can not, within the limits of such a review, be made the subject of critical consideration as such. And here it should be observed that nothing is done at Rothamsted in the way of manure or feeding-stuff analysis or seed control for any purposes external to those of the investigation. True it is that although, as has been said, a large amount of field, feeding, and analytical results still remains unpublished, yet fortunately a much larger amount has already been put on record. Hence it may be that some of those before me who are well acquainted with what has been written will be disposed to say, as I proceed, that we knew much of this before. On the other hand, probably a larger number of those who hear me are not so well acquainted with what has been written, and a still larger proportion of those who may read my lectures afterwards may feel that the outline only which I can give will serve the useful purpose of assisting them the more effectively to study the fuller published records. Indeed, the object I have had in view throughout has been to afford guidance for further study rather than to attempt the impossible task of giving anything like an adequate account of the results that have been obtained or of specifically indicating lines of inquiry for the future.

It will be appropriate here to explain that, meeting Professor Atwater two years ago in Germany, he urged the desirability of our sending to the World's Columbian Exposition pretty full illustrations of the Rothamsted work and results, to be exhibited side by side with those to be sent by the agricultural colleges and experiment stations of the United States; and that, on his way home some months afterwards, he paid a visit to Rothamsted, further to urge the plan on Sir John Lawes. A general assent to the proposition having been given, the question arose what sort of illustrations should be sent. Finally it was considered desirable to send such a series of exhibits as would serve to some extent as a substitute, in case I were not able to visit the United States; and which, in case I were able to give the proposed course of lectures, would be of service both to myself and to my hearers, in illustration of the facts and arguments I should have to adduce. Accordingly, it will be found that a large proportion of the 44 exhibits that have been sent have for their object the presentation to view of the results of the field experiments, of the nitrogen statistics of some of the crops, of the results of experiments on the question of the fixation of free nitrogen, and of results relating to the amount, and to the composition of rain, and of land drainage. There are also plans of the experimental fields, showing their areas, and the arrangement of the plats. Unfortunately, there is only one illustration relating to experiments on the feeding of animals. It was, however, intended that a pretty complete series relating to that most important subject should be prepared; but the enormous amount of time occupied, and the great hindrance to other work involved

in the preparation of the exhibits that have been sent, rendered it impossible to complete the original design. Some of the omissions in the execution of the intended list of exhibits will, however, be made good by illustrations embodied in my lectures.

With regard to the amount of the exhibits which have actually been sent, it may be observed that the quantity of wall space originally asked for was from 3,000 to 4,000 square feet, but the area actually covered is 4,786 square feet. To put the thing in another way, 4,000 square feet corresponds in area to a quarter of a mile in length a yard high; and the actual space covered (4,786 square feet) corresponds to rather more than three-tenths of a mile a yard high; and yet, as above stated, the original design has not been fully carried out.

As a preliminary to any detailed explanation of the scheme of the lectures I propose to give, it will be convenient to call attention to the general arrangement of the field experiments, and also to their extent and duration, as shown in the following table:

TABLE 1.—*List of the Rothamsted field experiments.*

Crops.	Commencing.	Number of years.	Area.	Number of plats.
			Acres.	
Wheat (various manures)	1843–44	50	11	34 or 37
Wheat alternated with fallow	1851	43	1	2
Wheat (varieties)	1867–68	15	4–8	about 20
Barley (various manures)	1852	42	4¼	29
Oats (various manures)	1869	[1] 10	0¾	6
Beans (various manures)	1847	[2] 32	1¼	10
Beans (various manures)	1852	[3] 27	1	5
Beans (alternated with wheat)	1851	[4] 28	1	10
Clover (various manures)	1848–49	[5] 29	3	18
Various leguminous plants	1878	16	3	18
Turnips (various manures)	1843	[6] 28	8	40
Sugar beet (various manures)	1870	5	8	41
Mangel-wurzel (various manures)	1876	18	8	41
Total		51		
Potatoes (various manures)	1876	18	2	10
Rotation (various manures)	1848	46	3	12
Permanent grass (various manures)	1856	38	7	22

[1] Including one year fallow.
[2] Including one year wheat and five years fallow.
[3] Including four years fallow.
[4] Including two years fallow.
[5] Clover 12 times sown (first in 1848); only 8 crops, 4 very small; one year wheat, five years barley, twelve years fallow.
[6] Including barley, without manure, three years, 1853-1855.

The general scope and plan of the field experiments has been to grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures; the same description of manure being, as a rule, applied year after year on the same plat. Besides the experiments on the growth of individual crops year after year on the same land, without and with different manures, so to speak, complementary experiments on the growth of crops in an actual course of rotation, without and with different manures, have been made; as also have others on the

mixed herbage of permanent grass land, both without and with various manures. And here it is to be observed that the arrangement of the manures is made entirely regardless of the comparative cost as between plat and plat, the question at issue being entirely one of constituents against constituents, and not of shillings against shillings, or dollars against dollars.

It is obvious that the results of field experiments with the individual crops of rotation, conducted as above described, must of themselves throw much light on the characteristic requirements of the particular crop under investigation; whilst those on the growth of crops in an actual course of rotation will serve to confirm and control those obtained with the individual crops, and will, in their turn, receive elucidation from the results with the individual crops. Then, again, the results of the experiments on the application of different manures to the mixed herbage of permanent grass land, which includes members of the botanical families that contribute some of the most important of our rotation crops, may, independently of their special value in reference to the main objects for which they were undertaken, be expected to afford interesting collateral evidence in regard to the requirements of individual plants thus grown in association, instead of alone, year after year, or in rotation, as in the other series of experiments. Obviously, too, the chemical, and in some cases the botanical statistics, of the various crops so variously grown, and the chemical statistics of the soils of the plats upon which they have been grown, must afford very important data for further study and elucidation.

An examination of Table 1 (p. 12) will show that the individual crops grown separately year after year on the same land include wheat, barley, and oats as members of the order Gramineæ; beans, clover, and other plants of the order Leguminosæ; turnips of the Cruciferæ; sugar beet and mangel-wurzel of the Chenopodiaceæ; and potatoes of the Solanaceæ. Then, the experiments on rotation include those with members of three different orders, turnips of the Cruciferæ, barley and wheat of the Gramineæ, and clover and beans of the Leguminosæ. Lastly, there are the experiments on the mixed herbage of permanent grass land, which includes, besides gramineous and leguminous plants, numerous species of other orders.

The first experiments were those with root crops, which were commenced in June, 1843, so that the present year, 1893, is the fifty-first of their continuance. The second were those on wheat, commenced in the autumn of 1843, so that the crop just harvested is the fiftieth grown in succession on the same land. The experiments with beans were commenced in 1847; but, for reasons that will be fully explained, they have not been continued up to the present time. Those with clover were commenced in 1848, and have been succeeded on the same land by others with various leguminous plants, which are still continued. Then, of the other more important series, those on barley were commenced in

1852, and are still in progress, the crop of the present year being, therefore, the forty-second in succession. Lastly, the experiments on an actual course of rotation were commenced in 1848, and are still continued, so that the present is their forty-sixth year, and those on the mixed herbage of permanent grass land were commenced in 1856, so that this year completes the thirty-eighth of their continuance.

It should be observed that many of the experiments were commenced without any idea of long continuance, and it was only as the results obtained indicated the importance of such continuance that the plan eventually adopted was gradually developed. It is, however, to long continuance that we owe some of the most interesting and the most valuable of our results, as will be fully illustrated as we proceed.

The table further shows the area and the number of plats under experiment in each case; and it may be stated that the total area under exact and continuous experiment has been for some years, and is at the present time, about 40 acres.

The point I have next to consider is, what is the most appropriate order in which to bring before you the field and other results relating to these various series of experiments. As you will readily understand must have been the case, our selection of crops for investigation was influenced by the actual practice in our own country, the separately grown individual crops being the chief of those entering into our rotations, whilst the course of rotation selected for study was that which is well known as the four-course, namely, roots, barley, leguminous crop (or fallow), and wheat. Obviously, therefore, the most natural order of illustration would be that indicated by the ideas and conditions in accordance with which the experiments have been arranged and conducted; and, notwithstanding the very widely differing conditions of the agriculture of our country and of yours, I think that the order so indicated will be found to be, upon the whole, not only the most convenient but the most instructive.

Even in our own country we have a great variety of soil and of climate, and accordingly great variety in crops, and in the order of their rotation, whilst in your more than fifty States and Territories, extending over such vast ranges of country, the mutual adaptations of soil and climate, and consequently the variety of crops and the order of their alternation with one another when so grown at all, are almost infinite. On the other hand, it is to be borne in mind that one of your most important crops at the present time is wheat, a member of the great and widely distributed gramineous family, and not only was it one of the most important of our crops until it came to be so largely grown by you, but it has been the subject of very special investigations, in various aspects, at Rothamsted. Then, maize and the sugar cane, and rice in a less degree, are extremely prominent American products, and they, like wheat, also belong to the great gramineous family. True, the conditions under which even wheat is grown are, as a rule, widely dif-

erent in the two countries, but in some important respects their characteristic requirements are very similar, whether grown in the one or in the other. Maize and the sugar cane, again, in spite of their characteristic differences of requirement, nevertheless show very characteristic similarity of requirement to that of wheat and its allies of the same family. Much the same may be said in regard to leguminous crops, and also to potatoes, as grown in the two countries.

Indeed, I think it will be recognized that, *mutatis mutandis*, the results which have been obtained under given conditions at Rothamsted are not without their significance and bearing, under the different conditions of the American continent, whilst the modes of experimenting adopted may afford suggestions for the conduct of more or less parallel investigations, varied, of course, according to the varying conditions.

In accordance with what has been said, the following list shows in outline the order in which it is proposed to treat of the crops experimentally grown at Rothamsted, and of the laboratory investigations connected with them. Lastly, it will be seen that the very important complementary subject of the feeding of animals will also be considered. It may be observed that Nos. 1 to 4 refer to the individual crops grown continuously, No. 5 to the same crops grown in rotation, and No. 6 to the feeding of animals.

1. Root crops: Common turnips, Swedish turnips, sugar beet, and mangel-wurzel, grown continuously.
2. Barley: Grown continuously.
3. Leguminous crops: Beans, clover, and various other Leguminosæ, mostly grown continuously; also the question of the fixation of free nitrogen.
4. Wheat: Grown continuously.
5. Rotation of crops: Root crops (Swedish turnips), barley, leguminous crops (or fallow), and wheat.
6. Results of experiments on the feeding of animals: For the production of meat, milk, and manure, and for the exercise of force.

Besides these six subjects, which were arranged to occupy the six lectures supposed to be given, there remained untouched the following:

The experiments with oats grown continuously.

Those with potatoes grown continuously.

Those on the alternation of wheat and fallow.

The very extensive series: On the mixed herbage of permanent grass land, including results as to the amounts of produce obtained, and those relating to its composition, both botanical and chemical.

Also, the extensive series on rainfall and drainage—their quantity and composition.

Accordingly, it was decided to give a seventh lecture, in which the results relating to the mixed herbage of grass land were summarized

as far as time would permit, and brief reference was also made to those on the alternation of wheat and fallow, and to those on the amount and composition of rain and drainage.

It is, however, not proposed to submit the material of this seventh lecture for publication. Indeed, as it seemed to be the general opinion of those I consulted on the subject at Washington and elsewhere that it was desirable that the matter published should give as complete a view as practicable of the investigations to which the lectures related, the space occupied necessarily extends considerably beyond that which would be required merely to put on record the matter actually given in the lectures. Hence, also, it has been thought desirable not to give the record in the form of lectures, but as so many separate subjects, each complete in itself, as far as space would permit.

SECTION I.

EXPERIMENTS WITH ROOT CROPS GROWN CONTINUOUSLY; BARNFIELD, ROTHAMSTED.

INTRODUCTION.

I imagine that root crops, results relating to which are the first to which I propose to call your attention, are, under existing conditions, of less importance in your agriculture than any other of the crops that will have to be considered. Still, I think that the facts which the investigations relating to them bring to light will be by no means without interest. I may mention that when in America some years ago—I think it was in the Eastern States—I was struck with the absence of these crops under conditions of soil, climate, and utility which seemed to me suitable for their growth; and I asked how it was that they were not brought in as elements of rotation. I was told that one potent reason was that no American would bend his back to hand-hoe! How far this was calumny I do not know, nor am I responsible in the matter. But when land which, with only sparse population, is devoted almost exclusively to the growth of cereals comes, owing to increased density of population and local demand for other crops and for feeding, to be brought into rotation, it is certainly worth considering whether, if the soil and climate are suitable, such crops could not be grown with advantage to the land by the conservation of its fertility, and also as a means of providing very useful food for stock for the production of meat and milk. True it is that over wide areas your climate enables you to grow large crops of maize as stock food, which we can not do. Indeed, maize with you, to a great extent, takes the place of root crops with us. Still it is a question whether, under favorable conditions of soil and climate, root crops might not advantageously have a more prominent place in your agriculture than they have at present.

The root crops, the conditions of growth and the composition of which we have now to consider, include members of more than one natural family of plants; and they are grown for, so to speak, certain intermediate parts and products, which are by cultivation very abnormally developed, while the crops are not allowed to ripen, but are taken when in a succulent and immature condition. We shall thus have interesting points of comparison, or contrast, brought out as to the conditions of growth of these crops, and of those to which we owe ripened products, such as cereal grains.

The crops to which I shall specially direct attention are some varieties of turnips, belonging to the order Cruciferæ, and two varieties of beet, namely, the feeding mangel and the sugar beet, of the order Chenopodiaceæ.

The introduction of turnips into our own rotations may be said to have been one of the most important improvements of modern times. The growth of the crop constitutes, indeed, an essential element, not only in the ordinary four-course rotation, but in all our varied rotations.

From certain characters of the turnip plant, and of other root crops, especially their abundant leaf surface, and from certain conditions of their growth, it has frequently been assumed that they are largely dependent on the atmosphere for their nitrogen, and that they are, in fact, thus collectors of nitrogen for the crops grown in alternation with them. But we shall see that experimental evidence does not support this conclusion, and that we must look in other directions for an explanation of the undoubted benefits of the growth of root crops in rotation.

The object to be attained in the cultivation of root crops is to encourage, by artificial means, a quite abnormal development of a particular part of the plant. If, for example, the turnip plant were grown for its natural seed-product oil, a heavier soil would be more suitable than when the object is to develop the swollen root. In our climate a biennial habit would be induced, and it would be so grown as to be exposed to the summer temperature at a later stage of the life history of the plant; that is, at the seed forming and ripening period. Under these circumstances there would be much less of fibrous root distributed through the surface soil; the main root would be much more fusiform, tapping rather than spreading laterally; the leaves and stem would be larger, both actually and proportionally to the root, and the enlarged root itself would serve as a store of material for the second or final growth.

To obtain the cultivated root, however, as grown as a rotation and food crop, the conditions required are very different. The seed is sown at a different period, and the character of the manuring and of the season of growth chosen are, in their conjoint influence, such as to favor a very abnormal accumulation of the store material in the root, and to secure that this development shall attain a maximum within the limits of the season. It will be seen, however, that the cultivated turnip very soon reverts to its more natural characteristics, if the mode of treatment be not such as to favor the artificial development.

The first results to be adduced relate to experiments with a variety of the common turnip, or *Brassica rapa*.

1. EXPERIMENTS WITH NORFOLK WHITE TURNIPS.

Root crops, whether common turnips, Swedish turnips, or mangel-wurzel, are, in ordinary practice, grown by the aid of large dressings of farmyard manure, with or without artificial manures in addition.

The farmyard manure is, in some cases, applied for the preceding grain crop, but more generally directly for the root crop itself. The following table shows the results obtained with Norfolk white turnips, both without manure and by 12 tons of farmyard manure, applied annually, for three years in succession:

TABLE 2.—*Produce of Norfolk white turnips.*

Seasons.	Roots.				Leaves.			
	Without manure.		With farmyard manure.		Without manure.		With farmyard manure.	
	Tons.	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
1843	4	3¾	9	9½	[1]	[1]	[1]	[1]
1844	2	4¼	10	15¼				
1845	0	13¾	17	0¾	0	14¼	7	7¾
Mean	2	7¼	12	8½	...	...	...	...

[1] Not weighed.

Thus the produce of this assumed restorative crop, when grown without manure, went down in the third year to practically nothing, only 13¾ cwt. per acre; whilst in the third year with farmyard manure there was more than 17 tons. But the amount varied very much according to season, it being nearly twice as great in the third year as in the first. Now, the farmyard manure employed would contain much more of nitrogen, and also of most of the mineral constituents, than the crops grown. The fact is that, independently of the great advantage accruing from the opportunity for cleaning the land, the value of the root crop in rotation is mainly to be attributed to the large amount of farmyard manure generally applied for its growth; to the large proportion of the constituents of the manure which remain and become slowly available to succeeding crops; to the large amount of the nitrogen and other constituents remaining in the leaf, which serve directly as manure again. Then they are gross feeders, so to speak, converting a large amount of manure into vegetable produce; whilst, when the edible portion, the root, is consumed by store or fattening stock, a very small proportion of the nitrogen and of other constituents valuable as manure is retained by the animal; the remainder, perhaps more than 90 per cent of the nitrogen, being voided, becoming manure again. When, however, roots are consumed for the production of milk, a much larger proportion is lost to the manure.

The next table (3) shows which constituent or class of constituents of the complex material, farmyard manure, has the most characteristic influence on the growth of the root crop. It shows the average yield, over four consecutive seasons, 1845–1848, of roots, of leaves, and of total produce, of Norfolk white turnips grown without manure and with a variety of artificial manures. The upper division shows the produce without mineral manure, and the lower division the mean produce of different mineral manures, namely: (1) Superphosphate of lime (plat

5); (2) superphosphate and potash salt (plat 6); (3) superphosphate, and potash, soda, and magnesia salts (plat 4).

TABLE 3.—*Norfolk white turnips grown year after year on the same land, Barnfield, Rothamsted—Results showing the effects of exhaustion and manures, four seasons, 1845–1848—Manures and produce per acre per annum.*

	Series 1 (no nitrogenous manure).		Series 3 (ammonium salts = 45 pounds nitrogen).		Series 4 (ammonium salts and rape cake = 135 pounds nitrogen).		Series 5 (rape cake = 90 pounds nitrogen).	
Without mineral manure (three years only, 1846–48):	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
Roots	1	4	1	7	5	10	6	11
Leaves	0	17	1	0	3	19	3	3
Total	2	1	2	7	9	9	9	14
With various mineral manures:								
Roots	8	4	9	18	10	5	11	0
Leaves	2	14	4	6	6	3	4	12
Total	10	18	14	4	16	8	15	12

The first point to notice is that on some of the manured plats there is an average of about 11 tons of roots and more than 4½ tons of leaves, giving of total produce per acre more than 15½ tons. Without manure, on the other hand, this assumed "restorative crop" yields an average of only 1 ton 4 cwt. of roots, 17 cwt. of leaves, and a total produce of only 2 tons 1 cwt. The character of the unmanured root was, moreover, totally different. It had more the shape of a carrot than of a turnip. Its composition was also totally different from that of the cultivated root, as is strikingly illustrated by the following figures, which relate to the crops of the third season of the experiments, 1845:

	Roots (per acre).		Nitrogen (per cent in dry matter).
	Tons.	*Cwt.*	*Per cent.*
Without manure	0	13¾	3.31
Farmyard manure	17	1	1.56
Superphosphate of lime	11	2	1.52

Thus, under the influence of manure there is a very large amount of nonnitrogenous substance accumulated, diluting, so to speak, the high percentage of nitrogen of the natural uncultivated root. There is, indeed, also much more nitrogen taken up by the cultivated plant; but in it there is, in proportion to the nitrogen, a large amount of other matters formed, the accumulation of which converts the plant into an important food crop. Even mineral manures alone, especially those which contain phosphates, have a very marked effect in inducing such accumulation; and it is preeminently by the action of such manures that a great amount of fibrous root is developed in the surface soil, under the influence of which more nitrogen, and at the same time more mineral matters, are taken up.

The results in the other columns of Table 3 (p. 20) show that the addition of nitrogenous manure, whether as ammonium salts or as rape cake, or both, gives a further increase in the produce of the roots. But the second line of each division of the table shows that a prominent effect of the nitrogenous manures is also largely to increase the production of leaf.

The next table (4) shows, first, the average proportion of leaf to 1,000 of root under the four characteristically different conditions as to manuring. It also shows the percentages of dry matter in the roots and in the leaves respectively, and the percentages of nitrogen and of total mineral matter (ash) in the dry matter. In the lower division of the table are given the amounts per acre of each of these constituents in the roots and leaves respectively, and the amounts per acre, more or less, in the leaf than in the root.

TABLE 4.—*Norfolk white turnips grown year after year on the same land, Barnfield, Rothamsted—Mean of plats 4, 5, 6 (four years, 1845–1848).*

	Series 1 (mineral manure alone).	Series 3 (mineral and ammonium salts = 47 pounds nitrogen).	Series 4 (mineral and ammonium salts and rape cake = 137 pounds nitrogen).	Series 5 (mineral and rape cake = 90 pounds nitrogen).
Leaf to 1,000 root	329	434	600	418
Dry matter:				
In root .... per cent	8.54	8.07	7.66	7.96
In leaf .... do	14.56	13.54	12.43	12.94
Nitrogen in dry:				
In root .... do	1.60	2.64	2.45	1.78
In leaf .... do	3.75	3.68	(3.68)	(3.68)
Mineral in dry:				
In root .... do	7.26	8.22	9.03	8.30
In leaf .... do	12.24	11.88	11.12	11.87
Dry matter, per acre:				
In root .... pounds	1,581	1,807	1,770	1,963
In leaf .... do	853	1,289	1,703	1,296
Leaf + or — root .... do	—728	—518	—67	—667
Nitrogen, per acre:				
In root .... do	25	48	43	35
In leaf .... do	32	48	63	48
Leaf + or — root .... do	+7	0	+20	+13
Mineral matter, per acre:				
In root .... do	118	148	160	165
In leaf .... do	100	151	187	151
Leaf + or — root .... do	—18	+3	+27	—14

Thus, with the Norfolk white turnip, we have less than one-third as much leaf as root without nitrogenous manure, but nearly two-thirds as much with the largest supply of nitrogen by manure—that is, with the greatest luxuriance of growth.

The economic importance of the difference in the proportion of leaf to root, under the influence of different conditions as to manuring, is illustrated by the other results given in the table, and similar results given in corresponding tables relating to Swedish turnips, sugar beet, and mangel-wurzel will show how great is the difference in this respect between different descriptions of root crops.

In the case of the Norfolk white turnips, not only is there a large proportion of leaf, but the leaf contains a very much higher percentage of dry matter than the root, and there is a very much higher percentage of both nitrogen and total mineral matter in the dry substance of the leaf than in that of the root.

The significance of these facts is more clearly brought out in the lower division of the table, which shows the amounts per acre, in root, and in leaf, respectively, of dry matter, of nitrogen, and of total mineral matter, under the different conditions of manuring; also the amounts of these in the leaf + or — the amounts in the roots.

It is seen that there was, in one case, that with the highest nitrogenous manuring, nearly as much dry or solid matter per acre in the leaf, which for the most part only becomes manure again, as in the edible part of the crop—the root. In three cases there is actually more of the nitrogen of the crop in the leaf, remaining for manure, than there is in the portion available as food. There is also, in two cases, more of total mineral constituents in the leaf than in the root.

2. EXPERIMENTS WITH SWEDISH TURNIPS.

The experiments with the Swedish turnip (*Brassica campestris rutabaga*) were made in the same field, on the same plats, and with, to a great extent, similar manures, as in the case of the Norfolk white turnips already considered. The mineral manures were in fact practically the same throughout, and the nitrogenous manures were nearly the same in the first two of the four years, 1849 and 1850, but in the second two no nitrogenous manures were used. Further, the results were obtained in the next succeeding four years to those in which the Norfolk whites were grown.

Table 5 shows the average amounts of produce—roots, leaves, and total—under the different conditions of manuring, over the four years, two with and two without nitrogenous manures.

TABLE 5.—*Swedish turnips—Results showing the effects of exhaustion and manures, four seasons, 1849–1852—Manures and produce per acre per annum.*

	Series 1 (no nitrogenous manure).		Series 3 (ammonium salts =41 pounds nitrogen, 1849 and 1850 only).		Series 4 (ammonium salts and rape cake =139 pounds nitrogen, 1849 and 1850 only).		Series 5 (rape cake=98 pounds nitrogen, 1849 and 1850 only).	
	Tons.	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
Without mineral manure:								
Roots	2	6	3	17	7	0	7	14
Leaves [1]	0	6	0	6	0	17	0	12
Total	2	12	4	3	7	17	8	7
With various mineral manures (plats 4, 5, and 6):								
Roots	7	5	8	18	12	2	11	9
Leaves [1]	0	10	0	11	0	19	0	15
Total	7	15	9	9	13	1	12	4

[1] Average of three years only, 1850-1852; leaves in 1849 not weighed.

Compared with the produce of the white turnip, that of the Swedish turnip shows upon the whole rather less root without nitrogenous manure, that is, with the mineral manure alone, owing to the gradual exhaustion of the nitrogen of the soil where none had been applied by manure for a number of years. But, on the other hand, there is with nitrogenous manures, in two cases out of three, more of the Swedish than of the white turnip root.

A very important point to notice is, that there was, even when there was more root, very much less leaf in the case of the Swedish turnip. Thus, whilst with the highest nitrogenous manure there was, with an average of 10¼ tons of the white turnip roots, nearly 6¼ tons of leaves, there was with the Swedish turnip, with more than 12 tons of roots, not quite 1 ton of leaf. Here, then, the result of growth is that almost the whole of the accumulation is in the food product—the root; and a very insignificant amount remains in the leaf, most of it simply to become manure again. This point will be more clearly illustrated by the results given in Table 6, which gives the leaf to 1,000 root, and the same particulars as before relating to the percentage composition of each, and to the amounts of the selected constituents per acre in each.

TABLE 6.—*Swedish turnips—Proportion of leaf to root, and selected constituents in root and leaf, per cent and per acre (mean of plats 4, 5, and 6; four years, 1849–1852).*

	Series 1 (mineral manure alone).	Series 3 (mineral and ammonium salts = 41 pounds nitrogen).	Series 4 (mineral and ammonium salts and rape cake = 139 pounds nitrogen).	Series 5 (mineral and rape cake = 98 pounds nitrogen).
Leaf to 1,000 root	69	61.8	78.5	65.5
Dry matter:				
In root .... per cent	11.59	11.51	10.54	10.89
In leaf .... do	13.81	13.08	12.97	13.19
Nitrogen in dry:				
In root .... do	1.40	1.69	2.19	1.84
In leaf .... do	3.95	4.07	4.11	4
Mineral matter in dry:				
In root .... do	4.38	4.49	4.83	4.66
In leaf .... do	12.16	11.85	10.54	10.59
Dry matter, per acre:				
In root .... pounds	1,879	2,245	2,840	2,769
In leaf .... do	154	166	270	227
Leaf + or — root .... do	—1,725	—2,079	—2,570	—2,542
Nitrogen, per acre:				
In root .... do	26	38	62	51
In leaf .... do	6	7	11	9
Leaf + or — root .... do	—20	—31	—51	—42
Mineral matter, per acre:				
In root .... do	83	102	139	130
In leaf .... do	19	20	29	24
Leaf + or — root .... do	—64	—82	—110	—106

It is seen that, instead of 300 to 600 parts of leaf for 1,000 of root, as in the white or common turnip, we have, with the Swedish turnip, in no case 100 of leaf to 1,000 of root. The highest proportion is 78½ to 1,000, and this is with the highest nitrogenous manuring and the most

luxuriant crops. It is further seen that the percentage of dry matter in the root ranged from $10\frac{1}{2}$ to $11\frac{1}{2}$, whilst in the white turnip it averaged only about 8 per cent. We have, therefore, not only a larger proportion of edible root, but that root contains a larger proportion of solid matter or food material. As with the Norfolk white, however, so also with the Swedish turnip, the leaf contains a much higher percentage of dry substance than the root, and the dry substance of the leaf contains a much higher percentage of both nitrogen and total mineral matter than does the dry substance of the root.

The lower division of the table shows, when compared with the corresponding particulars relating to the Norfolk white turnip, that with the Swedish turnip there was, with the highest manuring, fully one and a half times as much dry substance per acre in the root; that is, one and a half times as much food produced per acre as with the common turnip. Further, there is a quite insignificant amount of matter accumulated and remaining in the leaf, for the most part only serving as manure again.

Of the nitrogen again, there is, under all conditions of manuring, even those giving the greatest luxuriance, a very small proportion remaining in the leaf. The same is the case with the total mineral matter.

The question obviously suggests itself, If the Swedish turnip has all these advantages over the numerous varieties of the so-called common turnip, why are these ever grown? Why not always the Swedish turnip?

In the first place, soil and season have to be taken into account. Then the economy of the farm requires that descriptions should be selected that can not only be sown in due succession, but which will mature at different periods, so as to supply food for stock in due succession, and also frequently to get the crop early off the land, to leave it free for some other crop. Again, a comparatively large proportion of leaf serves as protection against frost while the crop is still in the field; and the storing qualities of the root have to be considered in connection with the character of the seasons of the locality. For example, on the light soils of Norfolk, which are very favorable for the development of root and but little for that of leaf, and where the roots can be largely consumed by sheep on the land without injury to its mechanical condition, the Swedish turnip is the predominant root. In the northeast and east of Scotland, on the other hand, several varieties of yellow common turnips are grown in much larger proportion, and a large amount of leaf is not recognized as a disadvantage. And here it may be observed that the higher the nitrogenous manuring and the heavier the soil the greater is the tendency to produce a large amount of leaf. Further, as a rule, the larger the amount of leaf remaining vigorous at the time the crop is taken up, the less fully ripe will be the roots; and, within limits, it is desirable, with a view to the storing qualities of the root, that it should not be too ripe.

After the four crops of Swedish turnips had been taken from the land, barley was grown for three years in succession without any manure, in order, as far as possible, to equalize the condition of the various plats, as affected by the previous manuring. It will suffice to say that the results clearly showed that there had been accumulation where rape cake had been applied. Then for five years in succession (1856–1860) Swedish turnips were again grown on the comparatively exhausted plats, much on the same plan as before, but with smaller amounts of nitrogen supplied. No special interest attaches to the results over these five years for our present purpose.

Table 7 shows the average produce per acre over the next ten years (1861–1870) again with Swedish turnips. During this period larger quantities of nitrogen were again applied, but for mineral manure superphosphate of lime was used alone; that is, without any further addition of either potash, soda, or magnesia.

TABLE 7.—*Swedish turnips—Results showing the effects of exhaustion and manures—Mean of ten seasons, 1861–1870—Manures and produce per acre per annum.*

	Series 1 (no nitrogenous manure).		Series 2 (sodium nitrate = 82 pounds nitrogen).		Series 3 (ammonium salts = 82 pounds nitrogen).		Series 4 (ammonium salts and rape cake = 180 pounds nitrogen).		Series 5 (rape cake = 98 pounds nitrogen).	
Without mineral manure:	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
Roots	0	11	1	1	0	13	4	9	4	15
Leaves	0	3	0	5	0	3	1	0	0	18
Total	0	14	1	6	0	16	5	9	5	13
With superphosphate of lime (plats 4, 5, and 6):										
Roots	2	9	5	8	4	9	7	9	6	8
Leaves	0	9	1	0	0	17	1	14	1	3
Total	2	18	6	8	5	6	9	3	7	11

The results of these experiments are little more than confirmatory of those which have gone before; but the amounts of produce are throughout on a lower level. This can only in part be attributed to the exclusion of potash from the manures. It is doubtless mainly due to the incidental circumstance that in growing the same description of crop, with the same comparatively limited and superficial root range, for so many years in succession the surface soil became less easily worked, and the tilth, so important for turnips, was frequently unsatisfactory, whilst for want of variety and depth of root range of the crop a somewhat impervious pan was formed below.

The fact is, however, of itself of considerable interest, as indicating one important and very beneficial influence of a rotation of crops. Indeed, we shall presently see that even the change to another description of root crop, with a totally different and much more extended root range, is accompanied with a much increased production over a given area by the use of the same manures.

Looking to Table 7, it is seen that there are now five series of plats instead of only four, nitrate of soda being applied on series 2 in amount

supplying the same quantity of nitrogen as in the ammonium salts on series 3. The result is a greater produce of both root and leaf than with the ammonium salts.

The superphosphate alone (see lower division of column 1) gives much less produce than the mineral manures in the series of four years before considered, doubtless to a great extent owing to the still further exhaustion of the available nitrogen of the surface soil. In fact, the surface soils in question showed on analysis lower percentages of nitrogen than those of any other experimental field at Rothamsted, a result which is quite consistent with the fact of the large amount of root distributed through the surface soil by the growing turnip. Again, consistently with this supposition and with the results that have gone before, there is still very marked, but somewhat reduced, effect from all the nitrogenous manures; and again, the amount of leaf is very small, but it is the greater the higher the nitrogenous manuring and the greater the luxuriance of growth.

Table 8 shows the proportion of leaf to 1,000 of root; also the percentages of dry matter and of nitrogen and mineral matter in the dry matter, and, as before, the amounts of each per acre in the roots and in the leaves.

TABLE 8.—*Swedish turnips (means of plats 4, 5, and 6; ten years, 1861–1870).*

	Series 1 (mineral manure alone).	Series 2 (mineral and sodium nitrate = 82 pounds nitrogen).	Series 3 (mineral and ammonium salts = 82 pounds nitrogen).	Series 4 (mineral and ammonium salts and rape cake = 180 pounds nitrogen).	Series 5 (mineral and rape cake = 98 pounds nitrogen).
Leaf to 1,000 root	184	185	191	228	180
Dry matter:					
In root .... per cent..	12.04	11.01	11.32	10.94	10.83
In leaf .... do....	14.93	14.46	14.24	13.78	14.66
Nitrogen in dry:					
In root .... do....	(1.40)	(1.69)	(1.69)	(2.19)	(1.84)
In leaf .... do....	(3.95)	(4.07)	(4.07)	(4.11)	(4.00)
Mineral matter in dry:					
In root .... do....	4.55	5.38	4.71	5.10	5.03
In leaf .... do....	11.64	10.62	12.23	11.54	11.27
Dry matter per acre:					
In root .... pounds..	629	1,285	1,084	1,777	1,511
In leaf .... do....	146	320	268	498	376
Leaf + or — root..do....	—483	—965	—816	—1,279	—1,135
Nitrogen per acre:					
In root .... do....	8.8	21.7	18.3	38.9	27.8
In leaf .... do....	5.8	13	10.9	20.5	15.1
Leaf + or — root..do....	—3	—8.7	—7.4	—18.4	—12.7
Mineral matter per acre:					
In root .... pounds..	28.9	71.1	53.6	94.2	76.6
In leaf .... do....	16.8	33.1	32.5	57.5	41.9
Leaf + or — root..do....	—12.1	—38	—21.1	—36.7	—34.7

With the soil gradually becoming closer and less favorable for root development, the proportion of leaf to root is somewhat higher.

It should be explained that the percentages given in parentheses are not the results of direct determinations in each particular case, but are deduced from comparable results. They are, however, undoubtedly near enough to the truth for the purpose of the present illustrations.

Again, we see much higher percentage of dry substance in the leaf than in the root; also much higher percentages of nitrogen and of total mineral matter in the dry substance of the leaf.

Looking to the lower division of the table, it is seen that there is here again, under all conditions of manuring, much more solid matter per acre in the root than in the leaf. There is also more nitrogen and more total mineral matter accumulated in the root, though the proportion of the nitrogen which is accumulated in the leaf is higher than in the previous experiments.

3. EXPERIMENTS WITH SUGAR BEET.

To the order Chenopodiaceæ and to the species *Beta vulgaris* we owe many varieties of sugar beet, and also many varieties of feeding beet or mangel-wurzel. Mangel-wurzel is a very important agricultural crop in our own country, whilst sugar beet is not; but as I believe trials have been made on the growth of sugar beet for the production of sugar in some of your States, I will, in the first place, illustrate by reference to our own experimental results, the influence of various manures on the growth of the sugar beet and on the production of sugar in it, and afterwards, in more detail, give somewhat similar results relating to the mangel.

The experiments with both crops were made in the same field and on the same plats as those on which first Norfolk whites and afterwards Swedish turnips had been grown. The last crop of Swedish turnips was taken in 1870, and sugar beet then followed for five years in succession—1871–1875, inclusive. Experiments with the mangel were next commenced in 1876, and have been continued up to the present time (1893), so that the eighteenth crop is now growing. It has been stated that by the continuous growth of the one description of crop, the Swedish turnip with one character and limited range of roots, the surface soil had become close and a somewhat impervious pan was formed below it. Therefore, before growing sugar beet, the land was plowed more deeply.

During the first three of the five years of sugar beet, the arrangement of the plats, and of the manures, was substantially the same as afterwards for mangels; but during the last two years of the five neither farmyard nor any other nitrogenous manure was applied, the object being to determine the effects of the unexhausted residue of the nitrogenous applications during the preceding three years.

Sugar beet has a very much more deeply penetrating root than the turnip, and more, even, than the feeding beet or mangel. In fact, great command of the resources of the soil and subsoil is a characteristic of the cultivated plant. The root found to give the highest percentage of sugar is very characteristically fusiform, and by careful selection of plants from which to grow seed varieties are obtained nearly the whole of the swollen root of which forms under the surface of the soil, the percentage of sugar being much lower in the above ground portion

exposed to light. To such perfection has the art of selection, cultivation, and acclimatization reached, that some descriptions, when grown in suitable soils and localities, will yield nearly, and sometimes quite, 20 per cent of sugar.

For brevity, and as such heavy manuring is not adopted for the growth of beet for the manufacture of sugar, the results obtained with farmyard manure will not be given in any detail. It may, however, be observed that, over the three years of the application, the average produce per acre of roots by farmyard manure alone was about 16 tons, which was raised to nearly 24 tons by the annual addition of 86 pounds of nitrogen per acre as nitrate of soda; to about 22 tons by the same quantity of nitrogen as ammonium salts; to nearly 25 tons by 98 pounds of nitrogen as rape cake, and to more than 25 tons by 184 pounds as rape cake and ammonium salts together. These facts are sufficient to show how powerful a feeder and grower is the sugar beet when liberally manured; and that, provided other supplies are not deficient, nitrogenous manures very greatly increase the produce.

The following table shows the average produce of sugar beets (in detail roots only, and in the summary roots and leaves) over the three years, the two years, and the five years, under three conditions of mineral manuring, each alone and each cross dressed, as indicated, by various nitrogenous manures:

TABLE 9.—*Sugar beet—Results showing the effects of exhaustion and manures—Manures and produce per acre per annum.*

Plat.	Standard manures.	Series 1 (standard manures only).		Standard manures and— Series 2 (sodium nitrate = 86 pounds nitrogen).		Series 3 (ammonium salts = 86 pounds nitrogen).		Series 4 (ammonium salts and rape cake = 184 pounds nitrogen).		Series 5 (rape cake = 98 pounds nitrogen).	
	Mean of 3 years, 1871–73, with nitrogenous manures (roots only):	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
5	Superphosphate	5	18	19	11	13	9	17	15	16	5
6	Superphosphate and potassium sulphate	5	6	17	19	14	16	22	3	17	4
4	Superphosphate, potassium and magnesium sulphates, and sodium chloride	6	9	19	15	15	3	22	2	18	9
	Mean of 2 years, 1874 and 1875, without nitrogenous manures (roots only):										
5	Superphosphate	5	15	8	15	7	11	10	16	8	9
6	Superphosphate and potassium sulphate	5	8	8	3	7	11	10	19	8	17
4	Superphosphate, potassium and magnesium sulphates, and sodium chloride	5	19	9	2	7	13	11	13	9	3
	Mean of 5 years, 1871–75 (roots only):										
5	Superphosphate	5	17	15	4	11	2	14	19	13	3
6	Superphosphate and potassium sulphate	5	7	14	1	11	19	17	14	13	17
4	Superphosphate, potassium and magnesium sulphates, and sodium chloride	6	5	15	10	12	3	17	18	14	14

TABLE 9.—*Sugar beet—Results showing the effects of exhaustion and manures—Manures and produce per acre per annum*—Continued.

SUMMARY—MEAN OF PLATS 6 AND 4 (ROOTS AND LEAVES).

	Series 1 (standard manures only).		Standard manures and— Series 2 (sodium nitrate = 86 pounds nitrogen).		Series 3 (ammonium salts = 86 pounds nitrogen).		Series 4 (ammonium salts and rape cake = 184 pounds nitrogen).		Series 5 (rape cake = 98 pounds nitrogen).	
Mean of 3 years, 1871–73:	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
Roots	5	18	18	17	14	19	22	3	17	17
Leaves	1	7	5	2	3	10	7	16	3	13
Total	7	5	23	19	18	9	29	19	21	10
Mean of 2 years, 1874 and 1875:										
Roots	5	14	8	13	7	12	11	6	9	0
Leaves	1	3	2	2	1	10	3	6	2	8
Total	6	17	10	15	9	2	14	12	11	8
Mean of 5 years, 1871–75:										
Roots	5	16	14	15	12	1	17	16	14	5
Leaves	1	6	3	18	2	14	6	0	3	3
Total	7	2	18	13	14	15	23	16	17	8

The table shows that, when superphosphate was used either without nitrogenous manure or with nitrate of soda, the produce was as great as when potash was applied in addition; but when the nitrogen was applied as ammonium salts, ammonium salts and rape cake, or rape cake, the addition of potash to the superphospate shows more effect; and it will be seen further on that in the case of the mangels in subsequent years, the effect of the potash was very much more marked; that is, when under the continuous use of superphosphate without potash the potash of the soil had doubtless become more and more exhausted. That the deficiency of produce is much less marked where the superphosphate is applied with nitrate of soda than where with ammonium salts or rape cake, is probably due to the roots of the plant penetrating more deeply under the influence of the more soluble and more rapidly distributed nitrate, with its more readily available nitrogen, thus securing a better command of the supplies of potash (and other constituents) in the lower layers of the soil and subsoil.

Turning to the summary at the foot of the table, which gives the average results over the three years for plats 6 and 4 (with potash supply), both without and with nitrogenous manures, it is seen that whilst the mineral manures alone give an average of less than 6 tons of roots, the addition of nitrate of soda raises the produce to nearly 19 tons, that of ammonium salts to nearly 15 tons, that of rape cake to nearly 18 tons, and that of rape cake and ammonium salts together to more than 22 tons. It is also seen that during the succeeding two years, when no further nitrogenous manure was used, there was still more or less increase, due partly to the manure residue of the previous applications and partly to the increased amount of leaf that had been annually returned to the land as manure, where nitrogenous manures had been

employed. Thus the average produce over the two years by the mineral manures, including potash, but without nitrogenous manure, was 5 tons 14 cwt.; raised where nitrate of soda had previously been applied, to 8 tons 13 cwt.; where ammonium salts had been used, to 7 tons 12 cwt.; where rape cake to 9 tons, and where rape cake and ammonium salts together, to 11 tons 6 cwt.

The summary further shows that, over the three years of the application of nitrogenous manures, the produce of leaf was raised from 1 ton 7 cwt. with the mineral manures alone to 5 tons 2 cwt. by the addition of sodium nitrate, to 3 tons 10 cwt. by ammonium salts, to 3 tons 13 cwt. by rape cake, and to 7 tons 16 cwt. by rape cake and ammonium salts together. Over the next two years, without further nitrogenous manuring, but with some nitrogenous manure residue, and increased return of leaf to the land, where nitrogenous manures had been applied, the produce of leaf was raised from 1 ton 2 cwt. by the mineral manure alone to 2 tons 2 cwt. where in addition nitrate of soda had previously been applied, to 1 ton 10 cwt. where ammonium salts had been used, to 2 tons 8 cwt. where rape cake, and to 3 tons 6 cwt. where rape cake and ammonium salts had been applied together.

The next table (10), which relates to the mean produce of plats 6 and 4 (with potash) over the three years during which the nitrogenous manures were annually applied, shows the proportion of leaf to 1,000 of root, some particulars of the percentage composition of the root and of the leaf, and the amounts of certain constituents per acre in the root and in the leaf.

TABLE 10.—*Sugar beet (mean of plats 6 and 4, three years, 1871–1873).*

	Series 1 (mineral manure alone).	Series 2 (mineral and sodium nitrate = 86 pounds nitrogen).	Series 3 (mineral and ammonium salts = 86 pounds nitrogen).	Series 4 (mineral and ammonium salts and rape cake = 184 pounds nitrogen).	Series 5 (mineral and ra] e cake = 98 pounds nitrogen).
Leaf to 1,000 root	230	269	232	354	205
Dry matter:					
In root ... per cent	18.75	16.83	18.16	17.04	17.88
In leaf ... do	14.65	11.19	12.12	10.20	11.28
Nitrogen in dry:					
In root ... do	.58	.95	.84	1.27	.82
In leaf ... do	2.18	2.61	2.30	2.76	2.34
Mineral matter in dry:					
In root ... do	4.11	5.13	4.75	5.59	4.54
In leaf ... do	23.83	22.13	23.47	22.08	22.86
Potash in dry:					
In root ... do	1.45	1.67	1.72	1.84	1.61
In leaf ... do	5.29	4.52	4.82	4.58	5.21
Phosphoric acid in dry:					
In root ... do	.57	.55	.52	.57	.56
In leaf ... do	.78	.67	.64	.62	.81
Dry matter per acre:					
Root ... pounds	2,463	6,996	6,086	8,444	7,096
Leaf ... do	435	1,248	934	1,768	925
Leaf + or − root ... do	−2,028	−5,748	−5,152	−6,676	−6,171
Nitrogen per acre:					
Root ... do	14.3	67	51.2	105.5	58.4
Leaf ... do	9.5	32.8	21.5	48.8	21.6
Leaf + or − root ... do	−4.8	−34.2	−29.7	−56.7	−36.8

TABLE 10.—*Sugar beet (mean of plats 6 and 4, three years, 1871–1873)*—Continued.

	Series 1 (mineral manure alone).	Series 2 (mineral and sodium nitrate = 86 pounds nitrogen).	Series 3 (mineral and ammonium salts = 86 pounds nitrogen).	Series 4 (mineral and ammonium salts and rape cake = 184 pounds nitrogen).	Series 5 (mineral and rape cake = 98 pounds nitrogen).
Mineral matter per acre:					
Root ....pounds..	101.2	364.2	288.5	469.6	322.1
Leaf ....do....	103.7	276.9	217.9	390	210.2
Leaf + or — root ..do....	+2.5	—87.3	—70.6	—79.6	—111.9
Potash per acre:					
Root ....do....	35.6	117.1	104.4	155.1	113.9
Leaf ....do....	23	56.4	45	81	48.2
Leaf + or — root..do....	—12.6	—60.7	—59.4	—74.1	—65.7
Phosphoric acid per acre:					
Root ....pounds.	14.1	38.8	31.5	48.3	39.4
Leaf ....do....	3.4	8.3	6	11	7.5
Leaf + or — root..do....	—10.7	—30.5	—25.5	—37.3	—31.9

The first line of figures shows a range of from 204 to 352 parts of leaf to 1,000 of root, according to the manure and the consequent degree of luxuriance and of maturity. The proportion of leaf was thus much higher than in Swedish turnips; it is also higher than in the mangel-wurzel, but much lower than in common turnips.

The percentage of dry matter in the root is more than twice as high as in common turnips, more than one and one-half times as high as in Swedes, and considerably higher than in the feeding beet or mangel-wurzel. It will afterwards be seen that this increased amount of solid matter in the root is chiefly sugar.

As in the case of the mangel the percentage of dry matter in the sugar-beet leaf is actually lower than in that of the turnips, and very much lower than in the root; while in the turnip it was very much higher in the leaf than in the root.

The percentage of nitrogen in the dry substance of the root is much lower than in the case of the turnip: and it is in a less degree lower than in the mangel root grown by the same manures. The percentage of nitrogen in the dry matter is very much higher in the leaves of the sugar beet than in the root.

The percentage of mineral matter in the dry substance of the leaf is 4 or 5 times as high as that in the root; in fact, the mineral matter constitutes more than one-fifth of the total dry substance of the leaf. It is higher than in the case of the mangels, and twice as high as that in either Swedish or common turnips.

Table 10 shows that the percentage of potash in the dry matter of the sugar-beet leaf is very much higher than in that of the root. Of phosphoric acid, on the other hand, the percentage in the dry matter of the leaf is but little higher than in that of the root, while in the

dry matter of both root and leaf it is very much lower than is that of potash.

It will be seen from the table that, notwithstanding the comparatively large proportion of fresh leaf to root, the proportion of the total solid matter of the crop which is accumulated and remains in the leaf is, owing to the very high percentage of solid matter in the root, and very much lower percentage in the leaf, much less than would be concluded from the weight of the fresh produce only. Thus, with the lowest proportion of leaf, as in series 5 with rape cake, there were more than 3 tons per acre of solid matter in the root, and much less than half a ton in the leaf; while, with the highest nitrogenous manuring, the greatest luxuriance, the heaviest crops, and the highest proportion of leaf to root, as in series 4 with rape cake and ammonium salts together, there are more than $3\frac{3}{4}$ tons of solid matter per acre in the root, and little more than three-quarters of a ton in the leaf. It will be seen farther on how large a proportion of the solid matter of the root of this highly artificial vegetable produce is sugar.

The table further shows the increase in the amounts of nitrogen per acre in both the roots and leaves where nitrogen was supplied.

A point of interest in regard to the amounts of nitrogen per acre in the crops is, however, that there was in every case very much more accumulated in the root than in the leaf, which is chiefly of value only as manure again.

It is further seen that with the same mineral, but varying nitrogenous supply, the amount of total mineral matter per acre in the roots was only 101.2 pounds without nitrogen supply, 364.2 pounds with nitrate of soda, 288.5 pounds with ammonium salts, 322.1 pounds with rape cake, and 469.6 pounds, or more than 4 cwt., with the rape cake and ammonium salts together. Lastly, the total amount of mineral matter per acre in the leaf was, with the very high percentage in the dry substance, very large; but it was in each case with nitrogenous supply considerably less in the leaf than in the root. It is remarkable that with the same mineral supply in each case there was without nitrogen less than 2 cwt. of mineral matter per acre per annum in root and leaf together, while with the highest nitrogenous supply in addition there was more than $7\frac{1}{4}$ cwt. of mineral matter removed in the crop. There is here evidence both of how liberal must be the supply of available mineral constituents for the luxuriant growth of the crop and how great will be the exhaustion of them if the crop be sold off the farm.

Bearing in mind that the same amount of potash was applied per acre in the case of each of the five series, it will be observed that the percentage of potash in the dry substance of the root was considerably higher in the four series with nitrogenous supply than in series 1 without it; and when we consider, as will be fully illustrated further on, that the amount of sugar produced depends very materially on the

amount of nitrogen taken up, and that a liberal supply of available potash has also much influence on the amount of sugar produced, it is what might be expected that, with liberal nitrogen supply and increased production of sugar, we should find an increased amount of potash taken up. In fact, the lower division of the table shows that, with the same potash supply by manure, there was, compared with the amount stored in the root without nitrogenous supply, more than three times as much where nitrate of soda was added, nearly three times as much where ammonium salts were used, about three times as much where rape cake was employed, and nearly four and one-half times as much where rape cake and ammonium salts were applied together, supplying an excessive amount of nitrogen. The actual amounts of potash per acre in the roots were, indeed, only 35.6 pounds per acre per annum without nitrogenous supply, 117.1 pounds with nitrate of soda, 104.4 pounds with ammonium salts, 113.9 pounds with rape cake, and 155.1 pounds with the excessive supply of nitrogen in ammonium salts and rape cake together. Although, as has been seen, the percentage of potash was very much higher in the dry substance of the sugar-beet leaf than in that of the root, the figures in the table show that under all conditions as to nitrogenous supply there was much less potash per acre in the leaf than in the root. As, however, the leaf would be returned to the land as manure, there should be no loss of the potash of the farm by the amount of it left in the leaf. And, again, as the very much larger amount of potash in the roots should, when consumed on the farm, be almost wholly recovered in the manure of the animals fed upon them, there should be but little loss to the farm of the potash they contained. If, however, either the roots or the leaves are sold off the farm, the exhaustion of potash may be very considerable.

Turning to the amounts of phosphoric acid, the supply of which was the same for each of the five series, it has been seen that the percentage of it in the dry substance of the roots varied comparatively little; but the actual quantities per acre in the roots varied very considerably, and to a great extent in proportion to the amounts of growth as influenced by the nitrogenous supply. It is further seen that the amounts of phosphoric acid remaining in the leaf are very small compared with those in the root.

It has already been shown when considering the results recorded in Table 9 (p. 28), relating to the selected artificially manured plats, that the produce over the two years after the cessation of the application of the nitrogenous manures indicated considerable increase over that where no nitrogen had been applied, due partly to the residue of the nitrogenous manures previously applied and partly to the residue (leaves, etc.) of the larger crops previously grown. It will be of interest here to show the average produce of roots on the different divisions of the farmyard manure plat over the three years of the direct application of

the manures and over the succeeding two years of manure and crop residue. It was as follows:

TABLE 11.—*Sugar beet—Average results for two and three seasons.*

	Series 1 (farmyard manure alone, 3 years only).		Farm-yard manure and— Series 2 (sodium nitrate=86 pounds nitrogen, 3 years only).		Series 3 (ammonium salts =86 pounds nitrogen, 3 years only).		Series 4 (ammonium salts and rape cake=184 pounds nitrogen, 3 years only).		Series 5 (rape cake =98 pounds nitrogen, 3 years only).	
	Tons.	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
Three years of direct application	16	6	23	16	22	6	25	2	24	18
Two years of residue of manure and crop	14	0	15	16	16	3	17	17	17	2
Difference	2	6	8	0	6	3	7	5	7	16

Thus, there was an average of little more than 2¼ tons of roots less over the two years of unexhausted residue of the farmyard manure than over the three years of its direct application. There was also less leaf over the two years of residue. It is seen, however, that on the divisions of the farmyard manure plat where artificial nitrogenous manures were used in addition there was an average of from 7 to 8 tons of roots less over the two years of residue than previously. There was also considerable reduction in the produce of leaf. Still, the greater produce over the two years of residue action, where the nitrogenous manures had been previously used in addition than where the farmyard manure had been used alone, show considerable effect from the residue, either of the artificial nitrogenous manures themselves or from their increased crop-residue; and so far as there is any direct effect from the manure residue of the previously applied nitrate or ammonium salts, it is probably chiefly due to nitrates being drawn up again from the subsoil. Even in the case of the rape cake, the residue effect is also doubtless largely due to crop residue, but to a considerable degree to manure residue also, a portion of the nitrogenous matter of such organic manures becoming very slowly available in the soil.

To sum up on this point: In the case of the nitrate and ammonium salts, the effect of residue will be in the least proportion due to manure residue, and in the greatest to crop residue. With such manures as rape cake, the effect will be due in a large proportion to manure residue, and also largely to crop residue. With farmyard manure, so far as there had been larger crops, there will be much crop residue; but a very large proportion of the effect on future crops is to be attributed to slowly decomposing manure residue.

The next table (12) shows for the produce of the two years without further application of nitrogenous manures the same particulars as to composition as Table 10 for the preceding three years, namely, the amount of leaf to 1,000 root and the percentages and the amounts per acre of certain constituents in the root and in the leaf. The results need not be considered in much detail.

TABLE 12.—*Sugar beet—(Mean of plats 6 and 4; two years, 1874–1875).*

	The mineral manures, every year, and—				
	Series 1 (no nitrogenous manure).	Series 2 (previously sodium nitrate).	Series 3 (previously ammonium salts).	Series 4 (previously ammonium salts and rape cake).	Series 5 (previously rape cake).
Leaf to 1,000 root	206	248	197	294	263
Dry matter:					
In root ... per cent	17.77	15.71	16.67	16.31	16.01
In leaf ... do	11.21	10.18	11.41	10.45	10.24
Nitrogen in dry:					
In root ... do	.66	.71	.84	.87	.80
In leaf ... do	2.47	2.65	2.61	2.85	2.74
Mineral matter in dry:					
In root ... do	4.27	5.15	4.94	5.37	5.41
In leaf ... do	22.05	22.64	21.30	21.01	22.14
Potash in dry:					
In root ... do	1.56	1.91	1.86	1.81	1.79
In leaf ... do	5.37	4.99	4.31	4.46	5.08
Phosphoric acid in dry:					
In root ... do	.54	.49	.55	.61	.58
In leaf ... do	.81	.71	.75	.76	.77
Dry matter, per acre:					
Root ... pounds	2,259	3,026	2,843	4,138	3,232
Leaf ... do	296	493	385	790	557
Leaf + or − root .. do	−1,963	−2,533	−2,458	−3,348	−2,675
Nitrogen, per acre:					
Root ... do	14.5	22.6	23.2	35.7	26.4
Leaf ... do	7.2	13	10.1	23.1	15.4
Leaf + or − root .. do	−7.3	−9.6	−13.1	−12.6	−11
Mineral matter, per acre:					
Root ... do	95.8	154.6	140.5	218.8	171
Leaf ... do	64.7	110.4	79.9	163.1	119.2
Leaf + or − root .. do	−31.1	−44.2	−60.6	−55.7	−51.8
Potash, per acre:					
Root ... do	35.3	57.7	52.9	75.1	57.8
Leaf ... do	15.9	24.6	16.6	35.2	28.3
Leaf + or − root .. do	−19.4	−33.1	−36.3	−39.9	−29.5
Phosphoric acid, per acre:					
Root ... pounds	12.3	14.9	15.7	25.2	18.9
Leaf ... do	2.4	3.5	2.9	6	4.3
Leaf + or − root .. do	−9.9	−11.4	−12.8	−19.2	−14.6

Excepting in the case of series 5, the proportion of leaf to root is considerably less over the two years, with the less supply of nitrogen within the soil, and the consequent much less luxuriance. There is, nevertheless, generally a lower percentage of dry substance in the root, doubtless owing to the less formation of sugar, with the less nitrogen available to the plant. There is also generally a somewhat lower percentage of dry or solid substance in the leaf over the two years of comparative exhaustion. Lastly, there is, where nitrogenous manures had previously been applied, generally a lower, and in some cases a considerably lower, percentage of nitrogen in the dry substance of the roots over the two years of only residual supply. The percentage of nitrogen in the dry substance of the roots is indeed very low over both periods, but especially in the second; and it will be seen further on that it is much lower than in either of the descriptions of roots cultivated for feeding purposes. In fact, so much is the sugar-forming

habit of the plant developed, and so largely does the amount of the nonnitrogenous substance—sugar—contribute to the percentage of dry matter, that the percentage of the nitrogenous bodies is relatively very low, even though a large amount of nitrogen may have been taken up over a given area. As in the case of the three years with direct nitrogenous manures, so now over the two years with only residual supply of nitrogen, the percentage of nitrogen in the dry substance of the leaf is very much higher than in that of the root. It is, however, in each series somewhat higher over the two years than over the three of direct supply, probably owing to somewhat less matured—that is, less exhausted—condition of the leaves over the two years.

Turning now to the percentage of total mineral matter in the dry substance over the two years, it is seen that in the root and leaf it is approximately the same over the two years as over the preceding three; and it is, as was the case over the three years, four or five times as high in the dry substance of the leaf as in that of the root.

Referring to the results given in the lower division of Table 12 (p. 35), relating to the amounts per acre of dry matter, nitrogen, and total mineral matter, it is seen that, comparing the other series with series 1, there is a considerable increase in the amount of dry substance per acre in the root, and some in the leaf also, due to nitrogenous residue. There is, moreover, notable increase in the amount of nitrogen stored up in both the root and the leaf over a given area, due to residue; but much less than there was under the influence of direct supply.

Comparing the average annual amounts of dry substance, of nitrogen, and of mineral matter per acre over the two years of the action of residue with those over the three years of direct supply, there is in the case of each of the series, 2, 3, 4, and 5, less than half as much dry matter per acre in the roots over the two as over the three years. There is about or less than half, and even only one-third as much nitrogen accumulated in the roots over the two years; and there is also generally less than half as much increase of nitrogen in the leaves over the two years. Further, though the supply was the same each year, there was less than half as much total mineral matter in the roots, and generally less than half as much in the leaves under the influence of the restricted supply of nitrogen and coincident restricted growth. In reference to these points it is to be borne in mind that the leaves were always returned to the land.

Whilst there is in the above facts clear evidence of considerable effect from previously unexhausted nitrogenous manure and crop residue, there is, at the same time, in the lower percentage of nitrogen in the roots, and in the much lower amounts per acre, both of dry substance and of nitrogen in the crops growing under the influence of only residual supply, clear indication that the nitrogenous accumulations available within the soil, whether from manure or from crop residue, were rapidly becoming exhausted.

The figures relating to the potash per cent in the dry matter of the

roots, and per acre in the roots, show (with the continued annual supply of potash), as in the case of the three years, a higher percentage in the dry matter the greater the luxuriance; that is, the greater had been the amount of nitrogenous manure and crop residue; and the percentages are higher over the two years, with the same supply of potash but much less available nitrogen, and much less luxuriance and total growth, than over the three years with the direct supply of nitrogen. On the other hand, the quantities of potash per acre in the roots, although much larger with nitrogenous residue and increased growth than with the mineral manure alone, are, with the much less growth than during the three years, generally only about half as much as over the preceding period; but, as above stated, the amount was greater in proportion to the dry substance produced, the supply of potash being the same, but the available nitrogen and the consequent growth much less. Further, as over the three years, so now over the two years with only residual nitrogenous supply, and very much less growth, the percentage of potash in the dry matter of the leaf is very much higher than in that of the root; but also as over the three years, the actual quantity of potash per acre in the leaf is very much less than that in the root.

As to the phosphoric acid, its percentage in the dry substance of the root is fairly uniform throughout the five series, with the same supply of it by manure, but with great difference in the available supply of nitrogen and in the amounts of growth. The amounts of phosphoric acid per acre in the roots are, however, by no means uniform in the different series, but have a very obvious relation to the quantities of dry substance grown. The percentage of phosphoric acid in the dry substance of the leaf is also pretty uniform throughout the different series, but the quantities per acre in the leaf, as in the root, have distinct relation to the amounts of growth. They are, however, in all cases much smaller than those in the root, and very much smaller than the amounts of potash in the leaf. The relation of the potash and phosphoric acid to the amount of substance grown will be further referred to presently.

The following table (13) shows in the upper division the percentage of sugar in the sugar-beet roots under the specified different conditions of manuring; in the second division the amounts of sugar yielded per acre (in pounds); in the third division the increase of sugar per acre by the nitrogenous manures; and in the bottom division the increased amount of sugar for one pound of nitrogen supplied in manure. The mean results are given for the three years of the direct nitrogenous supply, for the two years of residual supply only, and for the five years, three with and two without the direct supply. Further, the results are given both for plat 5 with superphosphate only as the standard or mineral manure, and for the mean of plats 6 and 4, the former with superphosphate and potash and the latter with superphosphate, potash, soda, and magnesia as the mineral manure.

TABLE 13.—*Sugar beet—Sugar (per cent and per acre per annum in the roots)—Averages of three years, 1871–1873; two years, 1874–75; and five years, 1871–1875.*

SUGAR.

Period.	Plat.	Standard manures.	Series 1 (standard manures only, every year).	Standard manures every year and— Series 2 (sodium nitrate =86 pounds nitrogen, 3 years only).	Series 3 (ammonium salts =86 pounds nitrogen, 3 years only).	Series 4 (ammonium salts and rape cake =184 pounds nitrogen, 3 years only).	Series 5 (rape cake =98 pounds nitrogen, 3 years only).
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Three years, 1871–73 ...	5	Superphosphate	13.08	10.66	11.88	9.89	12.17
	4 and 6	Superphosphate and potash	12.97	11.04	12.16	10.66	12.07
Two years, 1874–75 ...	5	Superphosphate	12.31	10.36	11.61	10.78	10.72
	4 and 6	Superphosphate and potash	12.05	10.60	11.99	11.17	11.22
Five years, 1871–75 ...	5	Superphosphate	12.77	10.54	11.77	10.25	11.59
	4 and 6	Superphosphate and potash	12.60	10.86	12.09	10.86	11.73
SUGAR PER ACRE.							
			Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Three years, 1871–73 ...	5	Superphosphate	1,731	4,661	3,563	3,886	4.407
	4 and 6	Superphosphate and potash	1,704	4,635	4,063	5,279	4,788
Two years, 1874–75 ...	5	Superphosphate	1,584	2,053	1,963	2,591	2.065
	4 and 6	Superphosphate and potash	1,531	2,045	2.047	2,825	2,262
Five years, 1871–75 ...	5	Superphosphate	1,672	3,618	2.923	3,368	3,470
	4 and 6	Superphosphate and potash	1,635	3,599	3,257	4,297	3,778
INCREASE OF SUGAR PER ACRE OVER SERIES 1.							
			Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Three years, 1871–73 ...	5	Superphosphate	....	2.930	1,832	2,155	2,676
	4 and 6	Superphosphate and potash	....	2,931	2.359	3,575	3,084
Two years, 1874–75 ...	5	Superphosphate	....	469	379	1,007	481
	4 and 6	Superphosphate and potash	....	514	516	1,294	731
Five years, 1871–75 ...	5	Superphosphate	....	1,946	1,251	1,696	1.798
	4 and 6	Superphosphate and potash	....	1,964	1,622	2,662	2,143
INCREASE OF SUGAR FOR 1 POUND NITROGEN IN MANURE.							
			Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Three years, 1871–73 ...	5	Superphosphate	....	34.1	21.3	11.7	27.3
	4 and 6	Superphosphate and potash	....	34.1	27.4	19.4	31.5
Five years, 1871–75 ...	5	Superphosphate	....	37.7	24.2	15.4	30.6
	4 and 6	Superphosphate and potash	....	38.1	31.4	24.1	36.4

It may in the first place be observed that the percentage of sugar is about one and one-half times as high as in mangel roots grown under similar conditions as to manuring. Referring to the results for the first three years, the table shows that the percentage of sugar is the highest in series 1—that is, without nitrogenous supply, with the least luxuriance, and the smallest and ripest roots—the mean for plats 6 and 4 amounting to 12.97 per cent. On the other hand, in series 4, with the highest nitrogenous manure, the greatest luxuriance, and the least maturity, the percentage is only 10.66. Comparison of the percentages of dry matter and of sugar show that the sugar constituted about or more than two-thirds of the total dry or solid substance of the root. As a rule, where nitrogenous manure was used there was a somewhat higher

percentage of sugar with than without potash supply. There was also generally a somewhat higher percentage over the three years of direct nitrogenous supply than over the succeeding two years.

Referring to the second division of the table, which shows the amounts of sugar per acre under the different conditions as to manuring, it is seen that over the three years the mean produce of plats 6 and 4, with potash, was, without nitrogenous manure, 1,704 pounds; with nitrate in addition, 4,635 pounds; with ammonium salts, 4,063 pounds; with ammonium salts and rape cake, 5,279 pounds, and with rape cake, 4,788 pounds. In other words, with little more than three-fourths of a ton of sugar per acre with the mineral manure alone, there was, with nitrogenous manure in addition, in one case nearly 2 tons, in two over 2 tons, and in one nearly 2½ tons of sugar produced per acre. Over the subsequent two years, without further nitrogenous supply, there was, however, about, or not much more than, less than half as much sugar yielded.

The third division of the table shows that, with superphosphate and potash as the mineral manure, there was, over the three years, an average annual increase of sugar yielded per acre, due to the nitrogenous supply, of 2,931 pounds by the nitrate, of 2,359 pounds by the ammonium salts, of 3,575 pounds by the ammonium salts and rape cake, and of 3,084 pounds by the rape cake. Over the succeeding two years, however, the increased production of sugar, due to the nitrogenous residue, was with the nitrate less than one-fifth, with the ammonium salts more than one-fifth, with the ammonium salts and rape cake little more than one-third, and with the rape cake alone less than one-fourth as much as over the three years with the direct supply of nitrogen.

Upon the whole, therefore, it is evident that even with a full supply of mineral manure the produce of sugar was small, and that the increased production of that nonnitrogenous substance was dependent on the available supply of nitrogen within the soil. Examination of the table will further show that where ammonium salts, ammonium salts and rape cake, or rape cake alone was employed there was considerably more sugar produced on plats 4 and 6, where potash was supplied, than on plat 5, where superphosphate was the only mineral manure.

Doubtless with the continued supply of superphosphate alone as the mineral manure, and the growth forced by nitrogenous supply, the amount of potash available within the range of the roots had become more or less exhausted. Where the nitrogen was applied as nitrate, however, there was no deficiency of sugar production with superphosphate only as the mineral manure, a result probably due, as already observed, to the greater range of the roots induced under the influence of the soluble and more rapidly distributed nitrate, thus securing a better command of the potash of the soil and subsoil.

The bottom division of the table illustrates very strikingly the interesting fact of the dependence of the amount of the nonnitrogenous substance—sugar—produce on the amount of nitrogen available

within the soil. Thus, taking the results for plats 6 and 4, with full mineral supply, including potash, there is, over the three years, for 1 pound of nitrogen supplied—when as nitrate, 34.1 pounds; as ammonium salts, 37.4 pounds; as rape cake, 31.5 pounds, and when applied in excessive amount in ammonium salts and rape cake together, 19.4 pounds of sugar produced. Taking the results for the five years, three with direct supply and two with residue only, the increased production of sugar for 1 pound of nitrogen supplied is somewhat greater, namely: With the nitrate, 38.1 pounds; with the ammonium salts, 31.4 pounds; with the rape cake, 36.4 pounds, and with the ammonium salts and rape cake together, 24.1 pounds. It will be seen, however, that when superphosphate without potash was used as the mineral manure the produce of sugar for a given amount of nitrogen in manure was, excepting in the case of the nitrate, distinctly less.

It is not only in the case of sugar beet that the amount produced of the special carbohydrate of the plant is largely influenced by the supply of nitrogen; it is so in the case of root crops generally, which may be fitly called sugar crops. As we shall see further on, the result is very similar in the case of grain crops, the produce of which is greatly increased by nitrogenous manures; and in their case it is the carbohydrates, starch and cellulose, that are chiefly produced. It is also much the same with potatoes, the increased production of starch being then the characteristic result. In fact, it will be found that nitrogenous manures are chiefly used for crops poor in nitrogen, the increased produce of which is characteristically that of nonnitrogenous bodies. Without attempting to give a physiological explanation of the result, it may at any rate be stated as a matter of fact that nitrogenous manures greatly increase the general vegetative activity of such plants, and, consequently, if the other necessary supplies are not wanting, the activity of the formation of their natural or characteristic products is enhanced.

It has been seen that the supply of potash, as well as of nitrogen, has much to do with the amount of root development, and the amount of sugar produced. The following table shows the amounts of sugar for 1 part of potash in the roots. The supply of potash was the same in all cases; in series 1, without any nitrogenous manure, but in the other series the nitrogenous manures as indicated, in each of the first three years. The results are the means of plats 6 and 4, over the three years with the direct supply of nitrogen, over the two years without further nitrogenous supply, and over the five years, three with and two without nitrogenous manures on series 2, 3, 4, and 5:

Sugar for one part of potash in the roots.

	Series 1, without nitrogenous manure.	Series 2, with sodium nitrate.	Series 3, with ammonium salts.	Series 4, with rape cake and ammonium salts.	Series 5, with rape cake.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Three years, 1871–73	47.9	39.6	38.9	34.1	42
Two years, 1874–75	43.4	35.5	38.7	37.6	39.1
Five years, 1871–75	46.1	38.6	38.9	34.9	41.3

In the first place, it is to be observed that the amount of sugar for 1 part of potash in the roots is considerably the greater where no nitrogen was supplied by manure; and where there was no luxuriance, and by far the ripest roots—conditions under which the sugar produced would presumably be the maximum for the amount of nitrogen available, and probably also the maximum for the amount of potash present in the roots. The lowest amounts of sugar for 1 part of potash are, on the other hand, in series 4, where there was excess of nitrogen, great luxuriance, the lowest maturation, and consequently the crudest juice. Comparing period with period, the least amount of sugar for 1 part of potash in the roots was generally over the two years with full supply of potash, but deficient supply of nitrogen and deficient yield of sugar. In the cases of most normal growth, it would seem that there were for 1 part of potash rather more than 40 parts of sugar in the roots. In reference to these results it is to be borne in mind that the percentage of potash remaining in the dry substance of the leaf where carbohydrates are so largely formed was much higher than in that of the root; though, as Tables 10 and 12 show, by far the greater part of the total potash of the crop was found in the root where is the great accumulation of sugar.

Below are shown the amounts of nitrogen recovered in the increased produce of the roots only, taking the mean of plats 6 and 4, with potash as well as superphosphate as the mineral manure. The results are given for the three years of the direct supply of the nitrogenous manures, and for five years, three with and two without the direct supply; and the figures show the amounts of nitrogen recovered in the increased produce of roots for 100 supplied in manure:

	Three years.	Five years.
	Per cent.	*Per cent.*
With nitrate of soda	61.3	66.9
With ammonium salts	42.9	49
With rape cake	45	52.7
With rape cake and ammonium salts	49.6	57.4

Obviously only the nitrogen in the roots can be credited as immediate return from the manure employed. It is seen that the highest amount recovered is from nitrate of soda, namely, 61.3 per cent over the three years and 66.9 per cent over the five years; next we have 49.6 per cent over the three years and 57.4 per cent over the five years with ammonium salts and rape cape; then 45 per cent over the three years and 52.7 per cent over the five years with rape cake; and lastly only 42.9 per cent over the three years and only 49 per cent over the five years with ammonium salts. These amounts are, however, higher than those obtained with wheat or barley, a result no doubt chiefly due to the period of accumulation and growth extending much later in the season than in the case of those grain crops; and hence also, no doubt, is to be explained the much greater accumulation of nitrogen under equal conditions of soil by maize than by either wheat or barley. I shall recur to this subject further on.

4. EXPERIMENTS WITH MANGEL-WURZEL.

We have now to consider the results of experiments with mangel-wurzel, a variety of beet largely used in some districts of our own country for feeding purposes. The experiments were made in the same field and on the same plats as those with the turnips and sugar beet; and, following the sugar beet, they were commenced in 1876 and are still continued; the crop of 1892 being therefore the seventeenth in succession. I propose to draw my illustrations from results obtained in the field during the seventeen years and in the laboratory during shorter periods.

Table 14 gives the average produce—roots, leaves, and total—over the seventeen years for 6 plats, each with five different conditions as to nitrogenous supply.

TABLE 14.—*Mangel-wurzel—Average produce of seventeen seasons, 1876–1892 (quantities per acre per annum).*

Plat.	Standard manures.	Series 1 (standard manures only).		Standard manures and— Series 2 (sodium nitrate=86 pounds nitrogen).		Series 3 (ammonium salts=86 pounds nitrogen).		Series 4 (ammonium salts and rape cake=184 pounds nitrogen).		Series 5 (rape cake=98 pounds nitrogen).	
	Roots:	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
1	Farmyard manure	15	10	21	8	21	1	23	16	22	18
2	Farmyard manure and superphosphate	15	15	22	8	20	6	22	16	22	10
3	No mineral manure	4	4	12	11	6	6	10	1	10	12
5	Superphosphate	4	15	14	14	8	1	10	17	11	12
6	Superphosphate and potassium sulphate	4	5	14	16	13	9	21	3	17	2
4	Superphosphates, potassium and magnesium sulphates, and sodium chloride	5	2	17	6	14	13	24	6	19	16
	Mean of 6 and 4	4	14	16	1	14	1	22	15	18	9
	Leaves:										
1	Farmyard manure	2	15	4	1	5	2	5	17	4	4
2	Farmyard manure and superphosphate	2	14	4	9	5	0	5	17	4	3
3	No mineral manure	0	19	3	1	2	14	3	18	2	18
5	Superphosphate	1	0	3	1	2	18	3	19	3	1
6	Superphosphate and potassium sulphate	0	18	2	15	2	14	5	3	2	18
4	Superphosphates, potassium and magnesium sulphates, and sodium chloride	1	1	3	11	2	14	5	3	3	6
	Mean of 6 and 4	0	19	3	3	2	14	5	3	3	2
	Total produce (roots and leaves):										
1	Farmyard manure	18	5	25	9	26	3	29	13	27	2
2	Farmyard manure and superphosphate	18	9	26	17	25	6	28	13	26	13
3	No mineral manure	5	3	15	12	9	0	13	19	13	10
5	Superphosphate	5	15	17	15	10	19	14	16	14	13
6	Superphosphate and potassium sulphate	5	3	17	11	16	3	26	6	20	0
4	Superphosphates, potassium and magnesium sulphates, and sodium chloride	6	3	20	17	17	7	29	9	23	2
	Mean of 6 and 4	5	13	19	4	16	15	27	18	21	11

A glance at the table shows that the produce of roots of the mangel-wurzel is on a much higher level than that of either common or Swedish turnips, and there is also much more leaf. There was, however, a general similarity in amount of produce obtained under similar conditions of manuring with the mangel as with the sugar beet. Compared with turnips, the mangel seed is sown earlier and the plant has a longer period of growth. It has a much more deeply penetrating taproot, throws out a less proportion of its feeding roots near the surface, and exposes a comparatively large area of leaf to the atmosphere. With its more extended root range it is less dependent on continuity of rain when growth is once well established, and it bears, or rather requires, for full growth a higher temperature than the turnip. These conditions determine in what localities it is most suitably grown in this country. But where the soil and climate are suitable very much larger crops can be obtained than of turnips. The mangel requires, however, very heavy dressings of manure if it is to yield full crops.

Table 14 (p. 42) shows that with farmyard manure alone, which was applied at the rate of 14 tons per acre per annum, there was an average produce of 15½ tons of roots, and that the addition of superphosphate of lime increased it very little. This result, compared with that of turnips, is quite consistent with the difference in the character and range of the feeding roots of the two crops, and it is also quite consistent with common experience in the matter.

Notwithstanding that the amount of farmyard manure employed would supply annually about 200 pounds of nitrogen per acre per annum, it is seen that the addition of specially nitrogenous manures greatly increased the crops. Thus the average produce was raised from 15 tons 10 cwt. to 21 tons 8 cwt. by the addition of nitrate of soda, to 21 tons 1 cwt. by ammonium salts, to 22 tons 18 cwt. by rape cake, and to 23 tons 16 cwt. by ammonium salts and rape cake together.

With purely mineral manure the produce of this more powerfully rooting plant is much higher than was obtained with Swedish turnips by the same manures. The addition of nitrogenous manures in some cases more than quadrupled the produce. Thus the average produce of plats 6 and 4, with potash as well as superphosphate as the mineral manure, was, with the mineral manure alone, 4 tons 14 cwt., with the addition of nitrate 16 tons 1 cwt., with that of ammonium salts 14 tons 1 cwt., with rape cake 18 tons 9 cwt., and with ammonium salts and rape cake together 22 tons 15 cwt.

With the comparatively limited growth of turnips, potash manures had little effect; but here, after years of further exhaustion of the potash within the soil, and with so much more vegetable matter produced, the deficiency of potash where it had not been applied is very obvious. Thus, with ammonium salts and superphosphate the average produce was only 8 tons 1 cwt., but taking the mean of plats 6 and 4, with the ammonium salts, superphosphate, and potash also, the average produce

was 14 tons 1 cwt. Again, with superphosphate and rape cake, the average produce was only 11 tons 12 cwt., but that of plats 6 and 4, with potash in addition, was 18 tons 9 cwt. Lastly, with ammonium salts, rape cake, and superphosphate, the average produce was only 10 tons 17 cwt., but that of plats 6 and 4, with potash in addition, was 22 tons 15 cwt., or more than twice as much.

In reference to the average results over the seventeen years shown in the table, it may be stated that in favorable seasons very much larger crops were obtained. Indeed, in several seasons more than 30 tons of roots have been obtained by farmyard manure and artificial nitrogenous supply in addition; while in one case with the full mineral manure, including potash, and the highest nitrogenous supply more than 37 tons were obtained.

The proportion of leaf to root will be considered further on; but the table shows that the actual amount of leaf was very much increased by the nitrogenous manures, and that with farmyard manure and the highest artificial nitrogenous supply there was an average of nearly 6 tons of leaf.

The lower division of the table shows, in several cases, an average total produce, root and leaf together, of nearly 30 tons, and in some years there has been more than 40 tons. The very great power of utilizing manure and of producing vegetable substance possessed by the mangel is thus strikingly illustrated.

It has sometimes been assumed, however, that, by virtue of the large amount of leaf surface which root crops expose to the atmosphere, they obtain a large amount of their nitrogen from that source. It is further assumed that, if a small quantity of nitrogenous manure be applied, so as to favor the early development of the plant, it will then obtain the remainder from the atmosphere. The results given in Table 15 afford pretty conclusive evidence against such a view. There is there given the average produce of mangel-wurzel—root, leaf, and total crop—over five years:

(1) By superphosphate of lime and potassium sulphate.

(2) By the same mineral manures, with, in addition, ammonium salts supplying 7.8 pounds nitrogen per acre per annum.

(3) The same mineral manures and ammonium salts, supplying 86 pounds nitrogen per acre per annum.

TABLE 15.—*Mangel-wurzel—Average produce, five years, 1876–1880 (quantities per acre per annum).*

Plat.		Roots.		Leaves.		Total.	
		Tons.	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
1	Superphosphate of lime and potassium sulphate	4	10	1	0	5	10
2	As 1, and 36½ pounds ammonium salts (= 7.8 pounds nitrogen)	6	0	1	6	7	6
3	As 1, and 400 pounds ammonium salts (= 86 pounds nitrogen)	14	0	2	16	16	16

Thus the annual application of 7.8 pounds of nitrogen increased the crop by only 30 cwt. of roots per acre per annum, and it may be mentioned that the increased yield of nitrogen in the crop was even less than that supplied in the manure. The application of 86 pounds of nitrogen, however, further increased the crop of roots by 160 cwt. more, or by 190 cwt. in all. It is obvious that the application of the small amount of nitrogen (7.8 pounds) did not enable the plant to take up any from the atmosphere, and that it required a further supply by manure to obtain a further increase of crop.

It can not be doubted that, beyond the small amount of combined nitrogen which annually comes down from the atmosphere in rain and the minor aqueous deposits, the source of the large amount of nitrogen of root crops is the store of it within the soil, whether this be due to less recent accumulations or to direct supply by manure. Further confirmation of the conclusion that the source of the nitrogen of root crops, as of cereals and some others, is the supplies within the soil, is to be found in the fact that, after many years of the growth of such crops by mineral manures without nitrogen, the surface soil showed a lower percentage of nitrogen than has been found in any of the other experimental fields. It is indeed certain that if root crops are to yield large amounts of produce they must find within the soil a large supply of available nitrogen. On the other hand, the large amounts of produce obtained by the aid of nitrogenous manures on plats to which no carbonaceous manure has been applied for about fifty years is evidence that the atmosphere is at any rate the chief, if not the exclusive, source of the carbon of the crops.

Table 16 (p. 46) shows the proportion of leaf to root and the amount and distribution of certain constituents in the root and in the leaf, respectively. The results relate to the mean produce of plats 6 and 4, with potash as well as superphosphate as the mineral manure, and they are given for each of the five series; that is, with the mineral manure alone, and with the various nitrogenous manures in addition. Further, the results are the averages for six years, 1878–1883:

TABLE 16.—*Mangel-wurzel—Results for six years, 1878–1883 (means of plats 6 and 4).*

	Series 1 (mineral manure alone).	Series 2 (mineral and sodium nitrate = 86 pounds nitrogen).	Series 3 (mineral and ammonium salts = 86 pounds nitrogen).	Series 4 (mineral and ammonium salts and rape-cake = 184 pounds nitrogen).	Series 5 (mineral and rape-cake = 98 pounds nitrogen).
Leaf to 1,000 parts of root	197	178	177	216	152
Dry matter:					
In root ... per cent	14.98	12.70	13.58	12.60	13.20
In leaf ... do	10.61	9.58	9.71	9.53	10.28
Nitrogen in dry:					
In root ... do	.88	1.34	1.13	1.55	1.20
In leaf[1] ... do	2.55	2.94	2.86	3.29	2.88
Mineral matter in dry:					
In root ... do	5.72	7.31	6.80	7.63	6.88
In leaf ... do	20.61	20.19	20.72	20.62	20.08
Potash in dry:					
In root[2] ... do	2.70	2.40	3.15	3.23	2.98
In leaf[2] ... do	5.15	1.92	4.08	3.48	3.99
Phosphoric acid in dry:					
In root[2] ... do	.66	.62	.60	.58	.63
In leaf[2] ... do	.69	.65	.65	.60	.61
Dry matter per acre:					
In root ... pounds	1,502	4,877	4,443	6,533	5,188
In leaf ... do	210	653	565	1,062	610
Leaf + or — root ... do	—1,292	—4,224	—3,878	—5,471	—4,578
Nitrogen per acre:					
In root ... do	12.9	64.4	49.2	97.4	61.2
In leaf[3] ... do	5.4	19.2	16.2	34.9	17.6
Leaf + or — root ... do	—7.5	—45.2	—33	—62.5	—43.6
Mineral matter per acre:					
In root ... do	84.4	350.6	296.9	481.4	348.4
In leaf ... do	42.2	131.7	117	217.6	121.3
Leaf + or — root ... do	—42.2	—218.9	—179.9	—263.8	—227.1
Potash per acre:					
In root[4] ... do	40.9	125.3	142	225	164.6
In leaf[4] ... do	10.8	13	23.8	38.2	25
Leaf + or — root ... do	—30.1	—112.3	—118.2	—186.8	—139.6
Phosphoric acid per acre:					
In root[4] ... do	10	32.6	26.9	40.4	35
In leaf[4] ... do	1.4	4.4	3.8	6.6	3.8
Leaf + or — root ... do	—8.6	—28.2	—23.1	—33.8	—31.2

[1] Determinations made on mixed samples of plats 4, 5, and 6.
[2] These results relate to plat 6 only.
[3] Calculated from the determinations made on mixed samples of plats 4, 5, and 6.
[4] Calculated from the percentage results relating to plat 6 only.

The first line of figures shows that the proportion of leaf to 1,000 parts of root ranged from 152 to 216, and that it was the highest with the highest manure, and the greatest luxuriance.

The proportion of leaf was considerably higher than in the case of Swedish turnips, but very much lower than with common turnips. With the same description of roots there will, however, generally be the higher proportion of leaf the heavier the soil, the wetter the season, the higher the nitrogenous manuring, and the less ripe the crop.

Referring to the percentage composition of the mangel root and leaf, it is to be observed that whilst with turnips there was a much higher percentage of dry substance in the leaf than in the root, there is in the mangels, as there was in the sugar beet, a considerably higher percentage in the root than in the leaf. The percentage of dry substance in

the mangel root is, in fact, considerably higher than in the Swedish turnip root, whilst the percentage in the mangel leaf is much lower than in the turnip leaf. The question suggests itself, to what extent this may be due to more complete exhaustion of the leaf, in the accumulation of the larger amount of reserve material, chiefly sugar, in the root.

The percentage of nitrogen in the dry substance of the root is much the higher, the higher the nitrogenous manuring; indeed it is with the highest supply of nitrogen, $1\frac{3}{4}$ times as high as with the mineral manure alone. It will be seen further on, however, that beyond comparatively narrow limits a high percentage of nitrogen may even be a disadvantage so far as the feeding quality of the root is concerned. As in the case of the turnips, the percentage of nitrogen in the dry substance of the leaf is very much higher than in that of the root; and it is the higher in the leaf, the less mature the root.

The percentage of total mineral matter is, on the average, about three times as high in the dry substance of the leaf as in that of the root. Further, the table shows that, excepting in the case of series 2, with nitrate of soda and much soda in the ash there was a higher percentage of potash in the dry substance of the leaf than in that of the root, but about the same percentage of phosphoric acid in the dry substance of the leaf as in that of the root. It is to be observed, however, that the percentage of potash in the dry matter of the mangel root is much higher than in that of the sugar-beet root, in which so much more sugar and with it so much more dry substance is produced. On the other hand, the percentage of potash in the dry substance of the mangel leaf is generally distinctly lower than in the case of the sugar beet.

Upon the whole the percentage results show the higher percentage of dry matter and the lower percentage of nitrogen in the dry matter, in both root and leaf, the riper the crop; also the lower percentage of total mineral matter in the dry substance of the root the riper the crop; and conversely, there is a lower percentage of dry matter and a higher percentage of both nitrogen and mineral matter in the dry substance the more luxuriant and less ripe the crop.

The lower division of Table 16 shows that whilst there was only about two-thirds of a ton of dry substance per acre in the root, that is, in the food product of the crop without nitrogenous manure, there were nearly 3 tons with the highest nitrogenous manure, and there was, besides, about five times as much dry substance per acre in the leaf of the larger as in that of the smaller crop. There is here again a striking illustration of the dependence of the amount of carbon assimilated from the atmosphere over a given area on the amount of nitrogen available to the plant within the soil. The quantity of dry substance produced per acre under the influence of the highest nitrogenous manuring would contain considerably more than 1 ton of carbon; indeed, the increased amount of carbon assimilated under the influence of the nitrogenous manuring would be not much less than 1 ton per acre.

The table further shows that with the highest nitrogenous manuring, the greatest luxuriance, and the lowest maturation of the crop there was more than six times as much solid matter accumulated in the food product. the root, as in the leaf; whilst in the other cases, with smaller crops and better maturation. there was from seven to eight times as much solid matter in the root as in the leaf. Again, notwithstanding the much higher percentage of nitrogen in the dry substance of the leaf than in that of the root, there was, owing to the small proportion of leaf, generally less than one-third as much nitrogen remaining in the leaf only for manure again as was accumulated in the edible root. Of total mineral matter there was also much less remaining in the leaf than was stored up in the root. Lastly, there was very much less of the potash of the crop, and very much less of the phosphoric acid also, in the leaf than in the root.

The next point to consider is, What proportion of the nitrogen of the manure, which is seen to be so effective, is recovered in the increase of the crop? Table 17 shows in the column headings the amounts of nitrogen supplied per acre per annum by manure in the case of each of the series 2, 3, 4, and 5, and below are given the amounts of nitrogen recovered in the increased produce of roots (the leaves being returned to the land) for 100 supplied in manure. Results are given for plat 5 with superphosphate alone as the mineral manure, for plat 6 with superphosphate and potash, and for plat 4 with superphosphate, potash, soda, and magnesia as the mineral manure. The results are the averages for six years, 1878–1883. They are calculated by deducting the amounts of nitrogen in the crops grown by the mineral manure alone from those obtained where nitrogenous manures were used in addition, the difference showing the increased amount of nitrogen in the crop due to nitrogenous supply, and the figures show the increased amount of nitrogen in the roots for 100 supplied in the manure.

TABLE 17.—*Mangel-wurzel—Nitrogen recovered in increase of roots for 100 parts in manure—Average for six years, 1878–1883.*

Plats.	Standard manures.	Standard manures and—			
		Series 2 (sodium nitrate = 86 pounds nitrogen).	Series 3 (ammonium salts = 86 pounds nitrogen).	Series 4 (ammonium salts and rape cake = 184 pounds nitrogen).	Series 5 (rape cake = 98 pounds nitrogen).
5	Superphosphate	57.7	29.7	25.1	38.5
6	Superphosphate and potassium sulphate	58.1	44.5	45.5	51.8
4	Superphosphate, potash and magnesium sulphates, and sodium chloride	61.7	40.1	46.4	46.8
	Means of plats 6 and 4	59.9	42.3	45.9	49.3

It should be stated that on the plats of series 1, with the mineral manures alone, there was obtained in the mangel roots an average of

only about 13 pounds of nitrogen per acre per annum. But it is to be remembered that the plats yielding these very small amounts, even in the powerfully rooted mangel, had been under experiment with roots for nearly forty years, during which time they had not received any nitrogen by manure. During the earlier years, however, the common and Swedish turnips yielded much more; but in recent years neither sugar beet nor mangel-wurzel, even with their greater powers of collection and growth than turnips, has removed so much nitrogen without nitrogenous manure as wheat or barley grown for more than thirty years in succession without artificial nitrogenous supply.

In the first place, the figures show that under each of the conditions of nitrogenous manuring there was more, and with the ammonium salts or rape cake very much more, of the supplied nitrogen recovered in the roots where potash as well as superphosphate was used than where superphosphate alone was employed as the mineral manure.

Comparing the average results of the two plats (6 and 4), where both potash and superphosphate were supplied, it is seen that the amounts of nitrogen recovered as increase in the roots for 100 supplied in manure were:

With nitrate of soda	59.9
With ammonium salts	42.3
With rape cake	49.3
With rape cake and ammonium salts	45.9

Thus, even under the most favorable conditions as to mineral supply, in three out of the four cases less than 50 per cent of the nitrogen supplied by manure was recovered in the increased produce of roots obtained by its use; and even with the most effective of the nitrogenous manures, the nitrate of soda, scarcely 60 per cent was so recovered. It is true that the nitrogen in the roots alone by no means represents the total quantity assimilated per acre, but as the leaves are annually returned to the land as manure it is clear that, taking the average over a number of years, it is only the amount in the roots that can be credited as immediate return from the manure employed. Where, however, large amounts of organic matter are returned to the soil more or less of the at first unrecovered constituents of the manure will remain for future crops.

Then, as to the less return in the roots from a given amount of nitrogen supplied as rape cake than as nitrate of soda, it should be borne in mind that, although the nitrogen of such organic manures only becomes comparatively slowly available, yet on that account the more remains in the soil as manure residue for future crops.

Finally, the question obviously suggests itself, What is the result when, instead of these artificial manures, a large amount of nitrogen is supplied in farmyard manure, which must always be liberally employed if heavy crops of mangel-wurzel are to be grown? In the first place, larger quantities of nitrogen would generally be applied per acre in

farmyard manure than in any of the artificial manures used; and the results obtained on the farmyard manure plats point to the conclusion that a much smaller proportion of that supplied would be taken up by the immediate crop than in the case of either nitrate of soda or ammonium salts, and even less than with rape cake. But a characteristic of farmyard manure is that it leaves a large but only slowly available residue within the soil. It is the nitrogen of the liquid dejections of the animals that is first rendered available within the soil, then that of the finely comminuted matter which passes, intermixed with some secretions, in the solid excrements, and finally that in the litter. It is, in fact, to the very large proportion of the constituents of the farmyard manure applied for root crops which remains available for future crops that an important part of the benefit of the growth of such crops in rotation is to be attributed. Indeed, it will be clearly seen from the evidence adduced that the root crops, which are assumed to perform the office of restoring the condition of the soil for the growth of the crops alternated with them, are themselves preeminently dependent on manure for their successful development. It is, in fact, the great power of utilizing the stores within the soil, due in some cases to accumulation, and in others to direct manuring, which these plants possess, growing and gathering nitrogen as they do after the period of its collection by the cereals, and the fact that it is only a very small proportion of their nitrogen and of their mineral matter which is carried off in the increase of the animals and so lost to the land that constitute a great part of the value of the root crops in rotation. When, however, roots are consumed for the production of milk, the loss to the manure will be greater than when they are consumed by either store or fattening animals.

It is a characteristic of the various descriptions of feeding roots, that they supply a large amount of the nonnitrogenous, respiratory, and fat-forming substance—sugar; indeed, about two-thirds of the solid matter of the mangel root is sugar. It will be of interest, therefore, to consider, as in the case of the sugar beet, both the percentage and the amounts of sugar produced per acre in the mangel under the different conditions of manuring. Table 18 gives particulars on these points. Average results for four years are given, and in each case for five selected plats, with different conditions of mineral and nitrogenous supply.

TABLE 18.—*Mangel-wurzel—Sugar (per cent and per acre per annum) in the roots—Average of four years, 1877–1880.*

SUGAR IN THE ROOTS.

Plat.	Standard manures.	Series 1 (standard manures only).	Standard manures and— Series 2 (sodium nitrate=86 pounds nitrogen).	Series 3 (ammonium salts = 86 pounds nitrogen).	Series 4 (ammonium salts and rape cake =184 pounds nitrogen).	Series 5 (rapecake= 98 pounds nitrogen).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Farmyard manure	8.04	6.69	7.20	6.66	7.28
2	Farmyard manure and superphosphate	8.10	6.42	6.80	6.63	7.27
5	Superphospate	9.74	7.07	8.68	7.45	8.82
6	Superphosphate and potassium sulphate	9.61	7.39	8.36	7.45	8.28
4	Superphosphate, potassium and magnesium sulphates, and sodium chloride	9.43	6.97	8	6.63	7.54
	Mean of 6 and 4	9.52	7.18	8.18	7.04	7.91

SUGAR PER ACRE.

Plat.	Standard manures.	Series 1	Series 2	Series 3	Series 4	Series 5
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	Farmyard manure	2,358	2,916	3,409	3,445	3,218
2	Farmyard manure and superphosphate	2,487	3,069	3,179	3,148	3,215
5	Superphosphate	965	2,436	1,696	1,888	2,166
6	Superphosphate and potassium sulphate	847	2,693	2,407	3,294	2,835
4	Superphosphate, potassium and magnesium sulphates, and sodium chloride	1,066	2,786	2.567	3,329	2,910
	Mean of 6 and 4	957	2,740	2,487	3,312	2,873

INCREASE OF SUGAR PER ACRE OVER SERIES 1.

Plat.	Standard manures.	Series 1	Series 2	Series 3	Series 4	Series 5
1	Farmyard manure	....	558	1,051	1,087	860
2	Farmyard manure and superphosphate	....	582	692	661	728
5	Superphosphate	....	1,471	731	923	1,201
6	Superphosphate and potassium sulphate	....	1,846	1,560	2,447	1,988
4	Superphosphate, potassium and magnesium sulphates, and sodium chloride	....	1,720	1,501	2,263	1,844
	Mean of 6 and 4	....	1,783	1,531	2,355	1,916

INCREASE OF SUGAR FOR 1 POUND NITROGEN IN MANURE.

Plat.	Standard manures.	Series 1	Series 2	Series 3	Series 4	Series 5
5	Superphosphates	....	17.1	8.5	5	12.3
6 & 4	Superphosphate and potash, etc.	....	20.7	17.8	12.8	19.6

It is seen that the percentage of sugar is higher in the roots grown by farmyard manure alone than in those with nitrogenous manures in addition. It is higher still when mineral manures are used alone, but here again it is reduced by the addition of nitrogenous manures. The fact is, that the lower the nitrogenous manuring the riper is the crop, and with this there is the higher percentage of sugar; and conversely, the higher the nitrogenous manuring the more luxuriant the growth, the less ripe the crop, and the lower the percentage of sugar.

Turning to the middle division of Table 18, it will be seen that, notwithstanding the lower percentage of sugar with high nitrogenous supply, the quantity of sugar produced per acre is greatly increased by such supply. Thus, referring to the results with farmyard manure, which is used so largely for the growth of the feeding beet or mangel, it is seen that, taking the average of four years, the annual produce of sugar was: With the farmyard manure alone, 2,358 pounds; with the addition of nitrate of soda, 2,961 pounds; of ammonium salts, 3,409 pounds; of rape cake, 3,218 pounds, and of ammonium salts and rape cake, 3,445 pounds. That is to say, the produce by farmyard manure alone was considerably more than 1 ton of sugar per acre, which was raised in two out of the four series by about half a ton by the addition of nitrogenous manure.

Referring now to the effects of mineral manure without and with nitrogenous supply, and taking the average of the two plats, 6 and 4, with full potash supply as well as superphosphate, it is seen that the mineral manure alone gives 957 pounds, or less than one-half ton of sugar per acre; and that with nitrogenous manures in addition the quantity is raised to 2,740 pounds by the nitrate, to 2,487 pounds by the ammonium salts, to 2,873 pounds by the rape cake, and to 3,312 pounds by the ammonium salts and rape cake together; that is, the produce of sugar was raised to 2½, and even to 3½, times as much by the addition of nitrogenous manure. In other words, as shown in the third division of the table, the increased produce of sugar by nitrogenous manure was 1,783 pounds by the nitrate, 1,530 pounds by the ammonium salts, 1,916 pounds by the rape cake, and 2,385 pounds, or considerably more than a ton, by the ammonium salts and rape cake together. Comparing these results with those on plat 5, with superphosphate without potash as the mineral manure, the evidence of the effects of potash on sugar production is very marked, for the increase is very much less under all the conditions of nitrogenous manuring, but especially with the ammonium salts, where the superphosphate was used without potash.

This is further strikingly illustrated in the bottom division of the table, which shows the increase of sugar produced for 1 pound of nitrogen supplied in manure. Thus, with full supply of potash, the increased production of sugar for 1 pound of nitrogen was, with the nitrate 20.7 pounds, with the ammonium salts 17.8 pounds, with the rape cake 19.6 pounds, and with the excess of nitrogen in the ammonium salts and rape cake together, only 12.8 pounds; but with the superphosphate without potash the increase was only 17.1 pounds with the nitrate, 8.5 pounds with the ammonium salts, 12.3 pounds with the rape cake, and only 5 pounds with the excessive amount of nitrogen in the ammonium salts and rape cake together.

Although it is clear, therefore, that the effect on sugar production of a given amount of nitrogen depended very materially on a liberal supply of potash, the results in the following table show that the amount

of sugar for one part of potash in the roots may vary very greatly accordingly as there is a deficiency or an excessive supply of potash. Thus, in the top line of the table we have the amounts of sugar produced for one part of potash in the roots with superphosphate of lime alone; that is, when there was obviously a deficient supply of potash for full sugar production under the influence of the amount of nitrogen available. Under these conditions it is to be supposed that there would be the maximum production of sugar for a given amount of potash present. The bottom line shows, on the other hand, the amounts of sugar produced for one part of potash in the roots, where potash was liberally supplied, when doubtless an excess was taken up; and, under these conditions, it is seen that the amount of sugar produced for one part of potash in the roots was, in all cases of nitrogenous supply and luxuriant growth, less than half as much as when there was a deficiency of potash. Comparing these results with mangels, with those relating to sugar beet, as given on page 40, it is seen that in the case of that crop, where the same amount of potash was supplied it would, with the much greater amount of sugar produced, not be so much in excess, the amounts of sugar for one part of potash in the roots being much greater under the corresponding conditions than with the mangels.

Sugar for one part of potash in the roots.

Plat.	Standard manures.	Series 1 (without nitrogenous manure).	Series 2 (with sodium nitrate).	Series 3 (with ammonium salts).	Series 4 (with rape cake and ammonium salts).	Series 5 (with rape cake).
5	Superphosphate	84	52.4	46.3	35.3	38.7
6 and 4	Superphosphate and potash, etc	23.4	21.9	17.5	14.7	17.5

To summarize in regard to the mangel-wurzel results on these various points, there is the more sugar produced the larger the amount of nitrogen supplied, but by no means in proportion to the amount supplied. The efficiency of a given amount of nitrogen is greatly dependent on the completeness of the accompanying mineral supply, and especially on that of potash. Again, the greater the excess of nitrogen the greater the luxuriance and the less ripe the roots, and the less is the amount of sugar obtained for a given amount of nitrogen supplied. Lastly, it will be remembered that with sugar beet much more sugar was obtained for a given amount of nitrogen in manure than the above figures show was the case with the mangel-wurzel.

CONDITION OF THE NITROGEN IN ROOTS.

An important point yet to consider is the amount and the condition of the nitrogen in roots of different descriptions, or grown under different conditions.

As is well known, in perfectly ripened seeds by far the larger proportion, and in many cases nearly the whole of the nitrogen exists as albuminoids. In ripened products, however, some, and in unripened

ones sometimes a large proportion, of the nitrogen exists as amides. Now, so far as present knowledge goes, it seems probable that it is only the nitrogen existing as albuminoid compounds that can contribute to the formation of the albuminoid compounds of animal bodies or of milk. It would seem not improbable, however, that some amide compounds may replace the albuminoids in supplying material for the transformations incident to the constant waste of the nitrogenous substances of the body, the products of which pass from it in the urine. Then again, besides albuminoids and amides, succulent or immature vegetable products may contain nitrogen as nitric acid or as ammonia unchanged from the condition in which it has been taken up by the roots of the plant from the soil, or the one transformed into the other.

The question as to the condition of the nitrogen in vegetable foods, and especially in such crude and immature products as our feeding roots, is therefore one of great importance. In the early reports of the Rothamsted feeding experiments, published more than forty years ago, we called attention to the fallacy of estimating the whole of the nitrogen of our stock foods as protein or albuminoid compounds, especially in the case of succulent and unripened products.

Table 19 gives results as to the condition of the nitrogen in Swedish turnips grown in the experimental rotation at Rothamsted in 1880; also in the mangels grown in the experiments in 1878, 1879, and 1880.

TABLE 19.—*Showing the condition of the nitrogen in Swedish turnips and in mangel-wurzel.*

	Total nitrogen.		Albuminoid nitrogen.		Per cent of the total nitrogen.						
					As albuminoids.						
	In fresh roots.	In dry matter.	In fresh roots.	In dry matter.	In marc.	In juice.	Total.	As amides.	As nitric acid.	Other forms.	Total.
Rotation Swedes, season 1880:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Unmanured	0.347	2.758	0.114	0.906	21.1	11.8	32.9	......	......	67.1	100
Superphosphate	.120	.984	.072	.590	26.8	32.3	59.1	......	......	40.9	100
Mixed manure	.171	1.539	.073	.655	18.1	24.4	42.5	......	......	57.5	100
Mangel-wurzel, 1878 (mineral manures and rape cake):											
Superphosphate	.211	1.520	.075	.541	14.2	21.3	35.5	......	......	64.5	100
Superphosphate and potassium sulphate	.197	1.618	.067	.555	17.3	16.9	34.2	......	......	65.8	100
Superphosphate, potassium and magnesium sulphates, and sodium chloride	.171	1.525	.045	.401	8.8	17.4	26.2	......	......	73.9	100
Mangel-wurzel, 1879 (mineral manures and rape cake):											
Superphosphate	.182	1.166	.079	.507	23.1	20.1	43.2	......	3.9	52.9	100
Superphosphate and potassium sulphate	.157	1.087	.071	.492	24.9	20.5	45.4	......	10.3	44.3	100
Superphosphate, potassium and magnesium sulphates, and sodium chloride	.136	1.010	.060	.444	21.3	23	44.3	......	13.3	42.4	100
Mangel-wurzel, 1880 (mineral manures and rape cake):											
Superphosphate	.165	1.344	.068	.554	20	21	41	40.5	11.2	7.3	100
Superphosphate and potassium sulphate	.151	1.145	.073	.554	24.5	23.9	48.4	38.9	......	12.7	100
Superphosphate, potassium and magnesium sulphates, and sodium chloride	.123	1.099	.056	.501	22.8	23.1	45.9	38.8	10.8	4.5	100

It should be explained that one portion of the rotation land has been entirely unmanured throughout, and that the roots so grown are quite abnormal, none of the characters of the cultivated root being developed under these circumstances. The results given relate to the roots grown in 1880, as the first crop of the ninth course. It is seen that with an abnormally high percentage of total nitrogen in the roots (0.347 in the fresh and 2.758 in the dry) there was also a high percentage of albuminoid nitrogen, which corresponded, however, to only 32.9 per cent of the total nitrogen. The next plat had received, for the roots, superphosphate of lime alone. Under these conditions the roots of the ninth course show a very low percentage of nitrogen in their dry substance (0.984), but 59.1 per cent of it existed as albuminoid compounds. Lastly, the third plat received for the roots of each course a complex manure, both mineral and nitrogenous. The percentage of total nitrogen in the dry substance of the roots (1.539), though not high, was nevertheless more than one and a half times as high as in the case of the roots grown by superphosphate alone, and the proportion of the nitrogen which was as albuminoids was only 42.5 per cent. Then again, it is seen that in the cultivated roots by far the larger proportion of the albuminoid nitrogen existed in the juice, that is to say was soluble, while in the unmanured or, so to speak, uncultivated roots a comparatively small proportion of the total albuminoids existed in the juice.

These results with Swedish turnips are very instructive, as showing how very dependent is the proportion of the nitrogen existing in the favorable food condition of albuminoid compounds on the conditions of the manuring and on the maturity of the crop.

In the results relating to the mangels the influence of season as well as of manure on the condition of the nitrogen is illustrated.

Three plats were selected for investigation which, with pretty full amounts of produce, would give roots of fairly good degree of maturation, namely, those manured with rape cake in addition to various mineral manures.

In 1878 there were somewhat under-average crops, with a large proportion of leaf; conditions indicative of comparative immaturity. Under these circumstances the percentage of total nitrogen in the roots was not high, but the proportion of the total nitrogen existing as albuminoids was low, namely, 35.5 and 34.2 per cent in two cases, and only 26.2 per cent in the third; but in this last case it was concluded that the determination was too low.

In the very wet and cold season of 1879 the crops were very small, and the percentage of total nitrogen was low, the result being, doubtless, partly due to loss of nitrogen by drainage. Under these circumstances the amounts of the total nitrogen found as albuminoids were 43.2, 45.4, and 44.3 per cent, or an average of about 44 per cent.

In 1880 the crops were much above the average, and the percentage of total nitrogen was low; and there was again under the better con-

ditions as to mineral manuring, that is, where potash was applied, more than 47 per cent of the total nitrogen albuminoid.

The bottom division of the table shows that in the crops of 1880, in which alone the amides were determined, the proportion of the nitrogen in that condition was about, or rather less than, 40 per cent of the total nitrogen, and not much less than that of the albuminoid nitrogen. It may be stated that, according to results given by Messrs. Ivey and Gray, the average composition of 11 New Zealand specimens of common turnips showed that the proportion of the nitrogen reckoned as "amides, etc." (including extractive matter), was 50.1 per cent of the total nitrogen, which is rather more than was found as albuminoids in the same roots and more than was found as amides in the Rothamsted mangels.

In all three cases in 1879, and in two in 1880, the amount of the nitrogen existing as nitric acid was determined. It is seen that with one exception, in which the nitrogen as nitric acid amounted to only 3.9 per cent of the total nitrogen, it ranged from 10 to 13 per cent of the total. Compared with those amounts, Messrs. Ivey and Gray found less than 1 per cent of the total nitrogen of the common turnips to exist as nitric acid, and not much more than 1 per cent as ammonia. It may be added that in some determinations made at Rothamsted in Swedes, the proportion of the total nitrogen as nitric acid was very much less than in the mangels.

Upon the whole, so far as the evidence at command enables us to judge, there is in mangels, with their more extended root range, greater power of accumulation, more luxuriant growth, and frequent greater immaturity when taken up, a somewhat less proportion of the total nitrogen in the albuminoid condition than in either common turnips or Swedes. There is also, probably, in mangels a less proportion of amide nitrogen, and pretty certainly a larger proportion of nitrogen as nitric acid, and in other forms.

APPROXIMATE AVERAGE PERCENTAGE OF DRY MATTER AND OF SUGAR IN VARIOUS ROOTS.

It has been stated that root crops, as grown for stock food, are essentially sugar crops. Not only, however, do the various descriptions of roots differ much in composition one from another, but the composition of one and the same description will vary very greatly under different conditions of growth, and of maturity of the roots accordingly. It will, nevertheless, be useful to give such an estimate as the evidence at command permits, of the approximate average percentages of dry matter, and of sugar, in different descriptions of feeding roots.

TABLE 20.—*Estimates of the approximate average percentages of dry matter, and of sugar, in different descriptions of roots.*

	Dry matter.	Sugar.	
		In fresh roots.	In dry matter.
	Per cent.	*Per cent.*	*Per cent.*
White turnips	8	3.5 to 4.5	44 to 56
Yellow turnips	9	4 to 5	44 to 56
Swedish turnips	11	6 to 7	55 to 64
Mangel-wurzel	12.5	7.5 to 8.5	60 to 68

Thus, then, even in common turnips, one-half or more of the total solid matter of the roots may be sugar. Of the total dry matter of Swedish turnips a larger proportion, and of that of mangels a larger proportion still, will be sugar; indeed, in well-matured mangels about two-thirds of the total solid matter may be sugar.

It may be assumed that in the cereal grains the proportion of albuminoid matter to the nonnitrogenous food material (starch, etc.) averages about as 1 to 6 (more or less), and that this is a proportion which is as a rule fairly favorable for the requirements of fattening animals. In roots the albuminoid ratio varies very greatly; but it is probably seldom more than as 1 to 12, and frequently as low as 1 to 20 or more. The ratio will generally be lower in Swedes than in common turnips and lower still in mangels.

It is obviously very essential to give with roots other foods which are richer in albuminoid substances, and which contain a higher proportion of albuminoid to digestible nonnitrogenous matters. Nevertheless, roots are, by virtue of the amount of sugar they supply, very valuable for meeting the respiratory requirements of the animals; also for fat forming and for milk production, when given in due admixture.

GENERAL CONCLUSIONS.

From all the illustrations that have been adduced it will be obvious that both the quantity and quality of the produce, and consequently its feeding value, will greatly depend on the selection of the best description of roots to be grown and on the character and the amount of the manures, and especially on the amount of nitrogenous manure, to be employed. It will at the same time be obvious that no hard and fast lines can be laid down in regard to these points. Independently of the necessary consideration of the general economy of the farm, the choice must be influenced partly by the character of the soil, but very much more by that of the climate. Judgment, founded, it is true, on knowledge, and aided by careful observation, both in the field and in the feeding shed, must be relied upon as the guide of the practical farmer.

Lastly, independently of the great advantage arising from the opportunity which the growth of roots affords for the cleaning of the land,

the benefits of growing the crop in rotation are due to the large amount of manure applied for its growth, to the large residue of the manure left in the soil for future crops, to the large amount of matter at once returned as manure again in the leaves, to the large amount of food produced, and to the small proportion of the most important manurial constituents of the roots which is retained by store or fattening animals consuming them, the rest returning as manure again; though when roots are used for the production of milk a much larger proportion of the constituents is lost to the manure.

SECTION II.

THE EXPERIMENTS WITH BARLEY GROWN CONTINUOUSLY; HOOSFIELD, ROTHAMSTED.

INTRODUCTION.

I propose next to consider results obtained at Rothamsted on the growth of barley for more than forty years in succession on the same land. The results of some laboratory investigations in connection with barley will also be adduced.

Barley, like wheat, is, as is well known, a member of the great gramineous order of plants to which we owe so many and such important economic products. In our own country and climate barley comes second to wheat in importance among the cereal crops we cultivate, though in the north oats gain in relative consideration.

Over large areas of America, with warmer and longer summers, another gramineous grain crop, maize, comes into prominence, and in warmer localities still grows the sugar cane. Indeed, it is to this family that we owe our chief starch and sugar yielding crops, and it is somewhat remarkable that the plants which, at any rate in temperate climates, come next in importance as starch and sugar yielding crops should belong to such widely different orders as the Solanaceæ, giving us the potato, the Cruciferæ, turnips, and the Chenopodiaceæ, the sugar beet, mangel-wurzel, etc., while the organs or parts of the plants which yield the products are also very different. In each case, however, it is the store of reserve material which the plant has accumulated for reproduction or for further growth which we turn to economic account. But not only does the gramineous family provide us with very important starch and sugar yielding crops, but it contributes a large proportion of the natural and cultivated herbage upon which animals of use to man are fed over large portions of the globe.

Although wheat and barley are thus closely allied botanically, and they have, moreover, in some respects very similar requirements as cultivated crops, yet it will be found that there are distinctions as well as similarities which it is important to recognize.

In our own country and climate, at any rate, wheat is almost invariably sown in the autumn, while barley is as generally not sown until the spring. Thus, wheat has four or five months for root development

and for gaining possession of range of soil before barley is sown. Under these circumstances, too, the conditions of soil most suitable to the two crops are very different. For wheat a comparatively heavy soil is adapted, and a fine tilth, encouraging superficial root development, is not desirable. For barley, on the other hand, a comparatively light soil is more appropriate, and a fine tilth is of great importance. In other words, with the characteristic habit of growth of the plant and the short period at its command for root development, a very permeable surface soil is a desideratum. In these facts we have the indication that wheat acquires a much greater root range, and consequently a command of the resources of a more extended range of both soil and subsoil, while barley must, in a greater degree, be dependent on the supplies within the surface soil, and so be the more susceptible to the influence of the exhaustion of the supplies within the surface soil. Bearing these various points in mind, we may now turn to the results of long-continued field experiments on the growth of barley by different manures and in different seasons, and to the evidence of the collateral laboratory investigations relating to the subject.

THE FIELD EXPERIMENTS ON BARLEY.

The Rothamsted field experiments on barley were commenced in 1852—that is, eight years later than those on wheat, but at the same time as that at which the arrangement of the plats in the experimental wheat field devoted to chemical or artificial manures became more systematic and permanent.

The barley crop of the present year, 1893, is the forty-second in succession on the same land. There are nearly thirty experimental plats. Two have been unmanured from the commencement. One has received farmyard manure every year, or rather one-half of it has, for after twenty years the plat was divided, one-half being still annually manured as before, and the other half then left unmanured, to test the effects of the unexhausted residue of the twenty years' previous applications of farmyard manure. The other plats have annually received artificial manures, for the most part the same, year after year, from the commencement. But there have been a few changes, some of which will be explained as we proceed.

RESULTS WITHOUT MANURE AND WITH FARMYARD MANURE.

Table 21 (p. 62) gives, both without manure and with farmyard manure, the produce of grain per acre in each of the forty-two years, and also the average produce over selected series of years, and over the period of forty years to 1891, inclusive. The first column gives the produce without manure. The upper portion of columns 2 and 3 gives the produce by farmyard manure for the first twenty years (1852–1871) over the whole plat. The lower portion of column 2 gives the produce on the half of the plat on which the application was still continued,

and that of column 3 the produce on the other half where the application was discontinued after the first twenty years, showing, therefore, the effects of the residue of the previous applications. Column 4 shows, for the later years, the excess of the produce on the plat where the application was continued over that where it was discontinued, and the last two columns show the increase over the unmanured produce, first by farmyard manure continuously applied, and secondly by the residue of the applications of the first twenty years.

First, referring to the produce without manure, it is seen that in two years, the third and fourth, the yield was over 30 bushels per acre; in six years during the first thirteen it was between 20 and 30 bushels, but it never afterwards reached 20 bushels, and in thirty-two out of the forty years the yield was less than 20 bushels; in eighteen of these it was less than 15, and in three less than 10 bushels. There was thus a very great variation in the amount of produce without manure from year to year, according to season. A glance at the figures, and especially at the average produce over successive series of years as given at the foot of the table shows, however, that, independently of these fluctuations due to season, there was a progressive decline due to exhaustion. It may be observed that there is, without manure, a decline in the produce of barley grain of 33.8 per cent over the second twenty years compared with the first twenty, and that this rate of decline is considerably greater than was found in the case of wheat. This result is doubtless due to the shorter period of growth and the greater dependence on the surface soil in the case of barley, and hence exhaustion is the sooner manifested.

TABLE 21—*Barley forty-three years in succession on the same land, Hoosfield, Rothamsted—Produce without manure and with farmyard manure, dressed grain per acre.*

Year.	Unmanured every year (plat 10).	Farmyard manure.				
		Every year, 1852–93 (plat 7–2).	Twenty years, 1852–71; unmanured 1872–93 (plat 7–1).	Plat 7–1 less than plat 7–2.	More than unmanured.	
					Manured every year (plat 7–2).	Manured twenty years, unmanured afterwards (plat 7–1).
	Bushels.	*Bushels.*		*Bushels.*	*Bushels.*	
1852	27¼	33		....	+ 5¾	
1853	25¾	36⅛		....	+10⅜	
1854	35	56⅜		....	+21⅜	
1855	31	50⅛		....	+19⅛	
1856	13⅞	32⅛		....	+18¼	
1857	26⅛	51¼		....	+25⅛	
1858	21⅛	55		....	+33⅞	
1859	13½	40		....	+26½	
1860	13¼	41⅝		....	+28⅜	
1861	16¼	54⅜		....	+38⅛	
1862	16½	49¾		....	+33¼	
1863	22⅞	59½		....	+36⅝	
1864	24	62		....	+38	
1865	18	52¾		....	+34⅜	
1866	15⅞	53⅛		....	+37¼	
1867	17⅛	45⅝		....	+28½	
1868	15⅝	43⅝		....	+28	
1869	15⅛	46⅞		....	+31¾	
1870	13½	47½		....	+34	
1871	16¾	54¼		....	+37½	
1872	10¼	38⅞	38¼	— 0⅝	+28⅝	+28
1873	14	54¼	47½	— 6¾	+40¼	+33½
1874	17⅝	64½	46½	—18	+46⅞	+28⅞
1875	12½	45¼	32½	—12¾	+32¾	+20
1876	12¾	45	31	—14	+32¼	+18¼
1877	17⅛	52	36	—16	+34⅞	+18⅞
1878	10	46¼	21⅞	—24⅜	+36¼	+11⅞
1879	6¼	36⅝	16⅝	—20	+30⅜	+10⅜
1880	18⅞	65¼	41⅝	—23⅝	+46⅜	+22¾
1881	17⅞	53¾	29¾	—24	+35⅞	+11⅞
1882	18⅜	60¾	35	—25¾	+42⅜	+16⅝
1883	16¼	58½	35½	—23	+42¼	+19¼
1884	13¾	57⅛	29	—28⅛	+43⅜	+15¼
1885	9¼	49¼	22	—27¼	+40	+12¾
1886	11	41¼	30½	—10¾	+30¼	+19½
1887	7½	26	10	—16	+18½	+ 2½
1888	12¼	45	24⅜	—20⅝	+32¾	+12⅛
1889	11¼	42	22¼	—19¾	+30¾	+11
1890	13	53	22⅜	—30⅝	+40	+ 9⅜
1891	15¼	43¾	33⅝	—10⅛	+28½	+18⅝
1892	14	59¾	30¾	—29	+45¾	+16¾
1893	8¼	43½	20¼	—23¼	+35¼	+12
1894	10	44⅝	23¾	—20⅞	+34⅝	13¾
AVERAGES.						
8 years, 1852–59	24¼	44¼		....	+20	
8 years, 1860–67	18	52⅜		....	+34⅜	
8 years, 1868–75	14½	49½	44⅝	(— 9½)	+34⅞	+30⅛
8 years, 1876–83	14⅝	52¼	31	—21¼	+37⅝	+16¼
8 years, 1884–91	11¾	44⅝	24¼	—20⅜	+33	+12⅝
20 years, 1852–71	20	48¼		....	+28¼	
20 years, 1872–91	13¼	49	30¼	—18¾	+35¼	+17
40 years, 1852–91	16½	48⅝	39¼	....	+32⅛	+22¾
Last 20 years, per cent + or — first 20 years	—33.8	+1.6	—37.3	....	....	....

Turn now to the produce by farmyard manure. As without manure, there is very great fluctuation from year to year according to season; but, instead of a gradual decline, there is an increase in the yield over the later years, due to the accumulation of the manure. There is, in fact, instead of a decline of 33.8 per cent, as without manure over the second compared with the first twenty years, an increase with farmyard manure of 1.6 per cent over the later period.

In four of the forty years the farmyard manure gave more than 60 bushels of barley per acre; in fifteen years, between 50 and 60 bushels; in fifteen, between 40 and 50 bushels; in five, between 30 and 40 bushels, and in only one year, below 30 bushels. The average yield was, over the first twenty years, 48¼ bushels; over the second twenty, 49 bushels, and over the forty years, 48⅝ bushels, against 16½ bushels without manure.

So much for the produce of barley obtained by the unusual application of 14 tons of farmyard manure per acre per annum for forty years in succession. It is estimated that the manure supplied about 200 pounds of nitrogen per acre per annum, or over twenty years, 4,000 pounds of nitrogen. It is further estimated that at the end of the first twenty years not more than 14 or 15 per cent of this large amount of nitrogen had been removed in the increase of crop. There must, therefore, have been a great accumulation of nitrogen and of other constituents within the soil, and analysis proved that this was the case. Indeed, it was calculated that, if there were no loss of nitrogen by drainage, by evolution of free nitrogen, or otherwise, and if the accumulated residue were as available as that which had already been effective, the produce should be maintained at the level of that of the first twenty years for nearly one hundred and fifty years more!

Let us see what was the result of stopping the application of manure on half the plat after the first twenty years. This is shown in the lower half of the table. Comparing the second and third columns, it is seen that there was a tendency to increase in yield where the application of the farmyard manure was continued and to decrease where it was discontinued. This result is brought prominently to view in column 4, which shows the reduction in the amount of produce on the manure residue plat compared with that where the application was continued.

The averages at the foot of the table show that over the first twenty years, with the continuous application, the yield was 48¼ bushels, while over the succeeding twenty years it was, where the application was continued, 49 bushels, but where it was discontinued only 30¼ bushels; showing, therefore, an average annual deficiency under the influence of the residue only of 18¾ bushels, or of 38.3 per cent.

Taking as the standard of comparison the unmanured produce (which, however, itself gradually declined), the last two columns show that over the first twenty years there was an average annual increase

of $28\frac{1}{4}$ bushels by the application of the farmyard manure, and that over the second twenty years there was an average annual increase ot $35\frac{3}{4}$ bushels where the application was continued and of only 17 bushels where it was discontinued.

It may be observed that over the whole period of forty years the total produce (grain and straw together) was without manure less than 1 ton per acre per annum, while with the farmyard manure it was $2\frac{3}{4}$ tons, and in some years it reached from $3\frac{1}{2}$ to $3\frac{3}{4}$ tons.

To sum up, in regard to the foregoing results, there was gradual exhaustion and reduction of produce without manure, and gradual accumulation and increase of produce with the annual application of farmyard manure. But when the application was stopped, although the effect of the residue from the previous applications was very marked, it somewhat rapidly diminished, notwithstanding that calculation showed an enormous accumulation of nitrogen as well as other constituents. Indeed, determinations of nitrogen in the surface soil, after the twenty years' application of farmyard manure, showed it to be nearly twice as high as on the unmanured plat. How, then, is the reduction of produce to be accounted for? The nitrogen of farmyard manure must obviously exist in very different conditions. That due to the urine of the animals will be the most rapidly available; that in the finely comminuted matter in the feces will be much more slowly available, and that in the litter still more slowly available. Hence, the small proportion that is at once effective and the very large amount that accumulates within the soil in a very slowly available condition. But the evidence at command leads to the conclusion that neither in the wheat field nor in the barley field does the accumulation within the soil account for the whole of the nitrogen supplied which is not recovered in the immediate increase of crop. Some is doubtless lost as nitrates by drainage, and some probably by evolution as free nitrogen. The fact of such losses is of considerable interest, but it is some consolation to believe that the loss will be proportionally very much less in ordinary farm practice, where the amounts of farmyard manure applied are much less, and where various crops, with different root ranges and different periods of accumulation, are grown.

RESULTS WITHOUT MANURE AND WITH ARTIFICIAL MANURES.

We have next to consider, What is the character of the exhaustion induced by the growth of the crop without manure, and to what constituent or constituents of farmyard manure its effects are mainly to be attributed? These points will be illustrated by the results given in Tables 22 and 23 (pp. 65, 66), which show the effects of various mineral manures, of various nitrogenous manures, and of combinations of the two:

TABLE 22.—*Barley forty-three years in succession on the same land, Hoosfield, Rothamsted—Dressed grain per acre; manure and produce per acre per annum.*

Year.	Series 1.				Series 2 (200 pounds ammonium salts=43 pounds N.).			
	Unmanured (plat 1).	Superphosphate (plat 2).	Potassium, sodium, and magnesium sulphates (plat 3).	Mixed mineral manure, 2 and 3 mixed (plat 4).	Alone (plat 1).	And—superphosphate (plat 2).	And—potassium, sodium, and magnesium sulphates (plat 3).	And—mixed mineral manure, 2 and 3 mixed (plat 4).
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1852	27¼	28⅝	26⅛	32¾	36⅞	38⅝	36	40¾
1853	25¾	33½	27⅝	35⅝	38⅝	40⅛	36½	38¼
1854	35	40⅝	36⅛	42	47¾	60½	50	60⅝
1855	31	36¼	34¾	37⅛	44½	47¾	44½	48⅜
1856	13⅞	17¾	16⅝	19¾	25	29⅛	28⅜	31¾
1857	26⅛	33¼	32	39¾	38⅞	56½	42⅜	57⅜
1858	21⅛	28¾	24¼	30⅞	31½	51⅜	34¼	51⅛
1859	13½	19⅝	15⅞	19¾	15⅜	34½	16⅞	34⅝
1860	13¼	15¾	15¼	18¼	26⅝	43⅜	28	43½
1861	16¼	25	18⅞	29⅜	30½	55	32¾	54⅝
1862	16½	21⅞	19¾	25⅛	31⅜	48⅝	35¼	47⅝
1863	22⅞	32⅜	27⅝	33	42⅝	61⅝	48⅝	55⅜
1864	24	30¼	26⅛	33¼	38⅞	58½	43⅞	55⅝
1865	18	22½	22	24⅜	29⅞	48⅜	33¼	46½
1866	15⅞	22⅜	19⅛	24	27⅛	50½	27½	47
1867	17⅛	24⅝	17	20⅞	30⅝	44	33	43⅞
1868	15⅝	18½	14¼	17⅝	20⅜	37⅝	25	34⅝
1869	15¼	18¼	18¾	22¼	27⅞	48	34¾	49¼
1870	13½	18	16¾	18½	27¾	41½	30⅞	38
1871	16¾	23⅛	19⅝	25	36⅜	45⅛	38⅛	46½
1872	10¼	15⅜	10½	14¼	26¼	39⅜	30⅜	36⅞
1873	14	19⅞	14⅞	20⅜	32⅜	50⅞	34⅛	46⅞
1874	17⅝	21¼	17⅞	19⅛	23⅛	42⅜	30⅝	45¾
1875	12½	14⅜	14⅞	17½	27⅜	37	29¼	35⅞
1876	12⅝	16⅛	12⅝	15⅝	21	33¼	23⅜	35⅝
1877	17⅛	23⅞	20⅛	23¾	35⅛	43⅞	41½	50½
1878	10	12⅛	7¾	11⅜	14⅞	31⅜	20⅛	33⅝
1879	6¼	7¾	6⅛	7¼	15¾	27⅞	16⅜	27⅜
1880	18⅞	28⅝	23⅞	30⅛	33⅞	55⅝	38⅛	54⅝
1881	17⅞	19¼	17⅛	17⅞	33⅛	43⅝	37⅜	42⅝
1882	18⅜	21⅞	19	23⅝	34⅞	45¼	39¼	50⅜
1883	16¼	22⅜	18⅜	24⅛	38⅞	49⅜	43⅝	52
1884	13¾	17⅝	13⅛	14¾	26½	29	31	42¼
1885	9¼	12⅛	7⅞	12½	15⅜	29	15½	32
1886	11	15⅜	11¾	11½	24½	37¼	19⅝	35⅞
1887	7½	9⅜	6⅝	8⅝	13¼	22⅛	16	22⅝
1888	12¼	20	13¼	18¾	20½	34¼	20	43½
1889	11¼	20	9	17¼	22½	35¼	19½	35¾
1890	13	16¾	9¾	17¾	24½	33½	23⅛	46⅜
1891	15¼	20¾	14⅜	20	29¼	51⅜	26	46½
1892	14	20¾	15⅛	21⅝	26¼	51	33⅞	50⅝
1893	8¼	11¾	7¾	10	11⅝	18⅛	16¾	30¾
1894	10	16¾	9½	13⅛	10½	34⅞	17¾	41⅜
AVERAGES.								
8 years, 1852-59	24¼	29¾	26¾	32¼	34⅞	44⅞	36⅛	45⅜
8 years, 1860-67	18	24⅜	20¾	26	32¼	51¼	35¼	49¼
8 years, 1868-75	14½	18⅝	15⅞	19⅜	27¾	42¾	31⅝	41¾
8 years, 1876-83	14⅝	19	15⅝	19¼	28½	41¼	32½	43¼
8 years, 1884-91	11¾	16½	10¾	15¼	22	34	21⅜	38⅛
20 years, 1852-71	20	25½	22½	27½	32½	47	35	46¼
20 years, 1872-91	13¼	17¾	13½	17¼	25⅝	38½	27¾	40¾
40 years, 1852-91	16½	21¾	18	22⅜	29	42¾	31⅜	43½
Last 20 years, per cent + or — first 20 years	—33.8	—30.4	—40	—37.3	—21.2	—18.1	—20.7	—11.9

TABLE 23.—*Barley forty-three years in succession on the same land, Hoosfield, Rothamsted—Dressed grain per acre; manures and produce per acre per annum.*

Year.	Series 3 (275 pounds sodium nitrate = 43 pounds N.).[1]				Series 4 (1,000 pounds rape cake = 49 pounds N.).[2]			
	Alone (plat 1).	Super phosphate (plat 2).	Potassium, sodium, and magnesium sulphates (plat 3).	Mixed mineral manure, 2 and 3 mixed (plat 3).	Alone (plat 1).	And—superphosphate (plat 2).	And—potassium, sodium, and magnesium sulphates (plat 3).	And—mixed mineral manure 2 and 3 mixed (plat 4).
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1852	44½	43¾	41¾	45⅓	39⅛	36½	33½	38
1853	40¾	42¼	41¼	44½	39⅞	36⅛	35¼	40⅛
1854	56⅝	63¼	51½	62¾	60¾	60⅝	56½	60¼
1855	48	50⅜	47¼	49⅝	48½	53¼	48⅞	51¾
1856	36¼	31½	25⅜	37⅝	36¾	37⅓	32⅝	35⅜
1857	49¾	66½	49⅞	64⅞	64⅛	62¼	60¼	62¼
1858	39⅜	56¼	40⅝	56¼	53¾	57⅜	52	57⅛
1859	21½	35⅞	20⅜	35¾	38¾	41	34⅛	35
1860	25⅜	43¼	30¾	46¼	31¾	36¾	35¼	40¾
1861	35	55¾	36⅞	55⅞	56½	56⅞	51⅛	53⅝
1862	31½	51	36¼	48¾	41	45	36	45½
1863	49	60½	54	59½	51⅞	55	53⅛	54½
1864	41¾	56⅞	44⅝	56⅜	48⅛	51¾	49⅜	53
1865	33¾	47½	34⅛	48⅞	45	46⅛	48¾	48⅛
1866	29⅛	50⅞	29¾	50⅞	45⅞	47½	43⅞	48⅝
1867	29¾	44¼	32⅞	45	38⅝	45½	38⅞	42⅝
1868	27	44	27½	45⅜	37	35¼	35⅛	36¼
1869	32⅛	48¼	33⅞	49⅞	42½	48¼	43⅝	52⅛
1870	29¼	46¼	32⅜	44½	41¾	41¾	38½	43¾
1871	39⅛	46½	36⅛	46	44	41¾	45⅜	47½
1872	26¾	38⅝	29¾	32	30⅛	33¼	27¾	33⅛
1873	37⅛	49	33½	46¾	45⅞	48¾	44¾	46½
1874	30⅛	53¾	32	51⅜	47⅛	49⅝	45¾	49¼
1875	29¾	38¾	27¾	42⅝	38¾	42⅝	33⅜	44¼
1876	19¼	31⅝	22¾	36⅜	36⅜	34½	31	35
1877	27½	46¾	38⅛	49½	44½	42¾	43⅛	47⅛
1878	15⅞	33½	20¼	31½	27¾	32	29¼	32½
1879	1[illegible]⅜	26⅜	16⅝	25½	27¼	28½	26⅝	31⅛
1880	38¼	57¼	41⅜	59⅜	50¼	55⅞	51¾	54⅞
1881	34¾	43¼	36½	47¼	41½	47⅞	40½	45
1882	34⅛	46¼	36⅛	50⅞	44¾	48¼	44¾	46⅝
1883	42⅞	53¼	44¼	54⅜	46	49	44¾	48¾
1884	34½	43¾	33½	45¼	40	43¼	38¼	40¾
1885	17½	38½	21½	31½	28⅜	34	28⅞	32⅜
1886	27⅛	40¾	26	36½	29½	31⅛	26½	28⅜
1887	19½	27	21⅛	25½	21	22⅞	19	21
1888	22¾	40	25¾	36½	36¾	39	34	38
1889	25¼	41½	24½	36	30⅞	33⅞	28½	30¼
1890	29½	47½	28	43¾	36	37¼	31½	33½
1891	30⅞	49¼	30¾	43¼	41	44⅞	42⅛	40¾
1892	38⅝	51⅝	36¼	48⅜	41½	46¾	40⅝	40¼
1893	14½	31¼	17⅞	29½	28¼	30¾	28½	31⅝
1894	14¾	41	19	45	35⅞	36¾	32	37⅜
AVERAGES.								
8 years, 1852–59	42⅛	48¾	39¾	49⅝	47¾	48	44⅛	47½
8 years, 1860–67	34⅜	51¼	37⅜	51⅓	44⅞	48	44½	48⅜
8 years, 1868–75	31⅜	45⅝	31⅝	44⅞	40⅞	42⅝	39¼	44⅛
8 years, 1876–83	29⅝	42¼	32	44⅜	39¾	42⅜	39	42⅝
8 years, 1884–91	25⅞	41⅛	26⅜	37¼	33	35¾	31	33⅛
20 years, 1852–71	37	49¼	37⅜	49¾	45¼	46¾	43⅝	47⅜
20 years, 1872–91	28⅜	42¼	29½	41¼	37⅛	40	35⅝	39
40 years, 1852–91	32¾	45¾	33½	45½	41¼	43⅜	39½	43¼
Last 20 years, per cent + or — first 20 years	—23.3	—14.2	—21.1	—17.1	—18	—14.4	—18.3	—17.7

[1] Six years, 1852-1857, ammonium salts, 400 pounds; ten years, 1858-1867, 200 pounds; 1868 and since, 275 pounds sodium nitrate.
[2] Six years, 1852-1857, rape cake 2,000 pounds, afterwards only 1,000 pounds, per acre per annum.

Results are given for 16 plats, arranged in 4 series of 4 plats each, and for each plat the produce—dressed grain per acre—is given for forty-two years in succession.

Series 1 comprises 4 plats without any nitrogenous manure, namely:

Plat 1.—Without manure.

Plat 2.—Superphosphate alone.

Plat 3.—Potassium, sodium, and magnesium sulphates.

Plat 4.—Superphosphate and potassium, sodium, and magnesium sulphates.

Series 2 comprises 4 plats, with the same four conditions as to mineral manures as series 1, with ammonium salts, supplying 43 pounds of nitrogen per acre per annum, in addition in each case.

Series 3, the same four conditions as to mineral manure, with, in each case, for six years, 86 pounds and, for ten years, 43 pounds of nitrogen per acre per annum as ammonium salts, and for the last twenty-six years 43 pounds as sodium nitrate.

Series 4, the same four conditions as to mineral manure, with, in each case, 2,000 pounds rape cake per acre per annum in the first six years, and 1,000 pounds each year since.

It may be mentioned that 1,000 pounds rape cake will, on the average, contain 48 to 50 pounds of nitrogen, or rather more than in the amounts of ammonium salts or nitrate used, though probably not more is rendered available within the years of application, but there will obviously be accumulation, and some cumulative action from year to year.

Time will not allow me to call attention in any detail to the produce of individual years, but it will be observed that under all conditions of manuring, whether without nitrogenous supply, as in series 1, or with it in the different forms and combinations, as in the other series, there is great fluctuation from year to year, according to season. Thus, without manure the produce ranges from 35 bushels in 1854 to only 6¼ bushels in 1879; with a full mineral manure (series 1, plat 4), from 42 bushels in 1854 to 7¼ bushels in 1879; with the full mineral manure and ammonium salts (series 2, plat 4) = 43 pounds nitrogen, from 60⅝ bushels in 1854 to 22⅝ in 1887.

As in the cases of series 3 and 4, more nitrogen was applied during the first six years than afterwards, the comparison of the produce in individual years at the beginning and at the end of the period have not quite equal significance; but it may be observed that, with the full mineral manure and ammonium salts at first and sodium nitrate afterwards (series 3, plat 4), the produce varied from nearly 65 bushels in 1857 to 25½ bushels in 1879 and 1887; and lastly, with the full mineral manure and rape cake (series 4, plat 4) it ranged from 62¼ bushels in 1857 to 21 bushels in 1887.

Looking to the average produce of each of the five eight-yearly periods, it is seen that under all conditions of manuring, even in the case of the rape cake with its annual accumulation, there is a general

tendency to reduction in produce from the first and second periods to the third and fourth, and still more in the fifth period compared with the third and fourth. Then, again, the average produce is in every case lower over the second than over the first twenty years. But examination of the details shows that there was, nevertheless, frequently more than average produce in individual years during the latter half of the whole period. There was, in fact, great fluctuation due to season; but there is also evidence of reduction due to exhaustion in some cases.

The bottom line of the tables, which shows the percentage reduction in the amount of produce over the second twenty years compared with the first twenty, enables us to discriminate in some degree between the effects of exhaustion and those of season.

It is seen that the 4 plats of series 1 show a reduction over the second twenty years of from about 30 to 40 per cent, or about twice as much as in the case of either of the other series. There is here evidence that in the case of series 1, without nitrogenous manure, much of the reduction over the second half of the period was due to nitrogen exhaustion.

In series 2, with ammonium salts, there is about 21 per cent reduction on plat 1, where the ammonium salts are used alone, nearly as much on plats 2 and 3 with defective mineral manuring, and only about 12 per cent where full mineral manures are used in addition.

In series 3, with sodium nitrate, there is a reduction of about 23 per cent where the nitrate is used without mineral manure, of 21 per cent where it is used with potash, soda, and magnesia, but without phosphate (plat 3), and of only 14 to 17 per cent where phosphates were used in addition to the nitrate.

Lastly, in series 4, with rape cake, which contains a considerable amount of mineral matter, there is a reduction of about 18 per cent on plats 1, 3, and 4, but of only about 14 per cent on plat 2 with superphosphate only as the mineral manure.

As already intimated, that there should be any reduction in the yield over the second half of the period where rape cake, with its annual residue and accumulation is used, is evidence that part of the reduction is due to an average of less favorable seasons over the later period; but that there should be the greatest reduction in series 1, where no nitrogen is supplied, is evidence of nitrogen exhaustion under those conditions; and that within series 2 and 3, respectively, there should be the greatest reduction, where the ammonium salts or nitrate are used without phosphates, is evidence of phosphoric acid exhaustion in those cases.

Leaving the results relating to the produce of each individual year, or of limited series of years, as given in Tables 22 and 23, a general view of the effects of the sixteen different conditions as to manuring is conveniently obtained in the Summary Table 24 (p. 69). There is there given the average produce over the forty years on each of the 16 plats.

The first column gives the results for the 4 plats of series 1, without nitrogenous manure; the second column those for series 2, with ammonium salts equal to 43 pounds nitrogen per acre per annum; the third those for series 3, first with ammonium salts and afterwards sodium nitrate, and the fourth those for series 4, with rape cake. The upper division of the table gives for each plat the average produce of grain per acre in bushels, the middle division the average produce of straw in pounds, and the lower division the average total produce (grain and straw together) in pounds.

TABLE 24.—*Summary showing the average produce of barley per acre per annum over forty years, by different manures.*

Plat.		No nitrogenous manure.	200 pounds ammonium salts = 43 pounds N.	275 pounds sodium nitrate[1] = 43 pounds N.	1,000 pounds rape cake[2] = 49 pounds N.
	Dressed grain per acre:				
1	Without mineral manure..........bush..	16½	29	32¾	41¼
2	Superphosphate ....do...	21¾	42¾	45¾	43⅜
3	Potassium, sodium, and magnesium sulphates............................bush..	18	31⅜	33½	39½
4	Superphosphate and potassium, sodium, and magnesium sulphates.......bush..	22⅜	43½	45½	43¼
	Straw per acre:				
1	Without mineral manure............lbs..	1,044	1,793	2,127	2,624
2	Superphosphate ....do...	1,210	2,674	3,018	2,792
3	Potassium, sodium, and magnesium sulphates ....lbs..	1,076	2,011	2,322	2,627
4	Superphosphate and potassium, sodium, and magnesium sulphates.........lbs..	1,279	2,904	3,186	2,875
	Total produce (grain and straw) per acre:				
1	Without mineral manure ....lbs..	1,976	3,420	3,964	4,953
2	Superphosphate ....do...	2,422	5,080	5,596	5,251
3	Potassium, sodium, and magnesium sulphates ....lbs..	2,079	3,773	4,208	4,876
4	Superphosphate and potassium, sodium, and magnesium sulphates.........lbs..	2,530	5,365	5,761	5,319

[1] Ammonium salts = 86 pounds nitrogen first six years; = 43 pounds next ten years; sodium nitrate = 43 pounds nitrogen each year since.
[2] 2,000 pounds rape cake first six years; 1,000 pounds since.

Referring first to the results on the four plats without nitrogenous manure, as given in the first column of the table, it is seen that plat 2, with superphosphate, and plat 4, with superphosphate and potassium, sodium, and magnesium sulphates, give considerably more produce than plat 3, with the potash, soda, and magnesia without phosphate. There is more of straw as well as grain and. of course, therefore, of total produce with than without the phosphate. There is, indeed, very marked effect by phosphatic manure, and very little by the alkalies.

The second column, with the same four conditions as to mineral supply, but with, in each case, 43 pounds of nitrogen per acre per annum as ammonium salts, shows a very great increase. Even with the ammonium salts alone there is a great increase; there is somewhat more on plat 3, where the alkalies are also applied, but very much more still on plat 2, where superphosphate, and on plat 4, where alkalies and superphosphate, are also used.

The third column shows that, with a larger amount of nitrogen supplied in the first six years and with sodium nitrate instead of ammonium salts in the later years there is still greater increase; and again, the increase is by far the greater where the superphosphate is used.

The four plats of series 4, with the rape cake, show a much greater uniformity of result with the different mineral manures. Still the two phosphate plats (2 and 4) give more produce than the two without phosphate. Referring to the produce of grain in illustration, it is seen that plats 1 and 3, with rape cake without superphosphate, give considerably more produce than the same plats (1 and 3) in either series 2 with the ammonium salts, or in series 3 with sodium nitrate. The explanation of this is that the rape cake itself contains phosphates. On plats 2 and 4, on the other hand, where phosphates are added, there is about as much produce in series 2 with the ammonium salts, and more in series 3 with the nitrate, than in series 4 with the rape cake.

Thus, then, while there is evidence that the phosphate of the rape cake was effective when none was otherwise supplied, when it was so applied in addition there was more effect with the nitrate with its more rapidly available nitrogen than with the rape cake with its greater actual amount of nitrogen, but in a less rapidly available condition.

Comparing the produce of plat 2 with superphosphate without potash with that of plat 4 with superphosphate and potassium, sodium, and magnesium sulphates in addition, it is remarkable that, both in series 2 with the ammonium salts and in series 3 with nitrate of soda, there is, over the whole period of forty years, almost identically the same amount of barley grain without as with the potash. There is, however, rather more straw and total produce with than without the potash. Thus we have, with the ammonium salts, an average of 42¾ bushels without potash and 43½ bushels with potash; and with the nitrate of soda 45¾ bushels without and 45½ bushels with potash. Of straw, however, there is, with the ammonium salts, an average of 2,674 pounds without and 2,904 pounds with the potash, and on the nitrate plats 3,018 pounds without and 3,186 pounds with potash.

It will afterwards be seen that where nitrogen and phosphoric acid were liberally supplied without potash the available potash of the soil itself became deficient, though this deficiency was, to the last, comparatively little manifested in the produce of grain. It is obvious, however, that with gradual reduction in the amount of total plant the yield of grain must also in time materially diminish.

So much for the influence on the barley crop, of different conditions of manuring, each continued for more than forty years, on the same plat, and in a field of somewhat heavy loam with a raw clay subsoil and chalk below, giving good natural drainage.

It is seen that nitrogenous manures alone had much more effect than mineral manures alone. It was obvious, therefore, that the exhaustion induced by the continuous growth of the crop was characteristically that of nitrogen.

Both with and without nitrogenous supply phosphates were more effective than potash salts, showing that the available store of phosphoric acid in the soil became deficient sooner than that of potash. With the shorter period of growth of barley than of wheat, and its greater proportion of surface rooting, both nitrogenous and mineral exhaustion are sooner developed; and so far as mineral exhaustion is concerned the available supply of phosphoric acid was sooner exhausted than was that of potash. Indeed, in ordinary agricultural practice it is clearly established that superphosphate is more effective with the spring-sown than with the autumn-sown cereals.

INFLUENCE OF SEASON ON THE AMOUNTS OF PRODUCE.

It has been seen that there were, under all conditions of manuring, very great variations in the amount of produce from year to year, according to season. The extent and character of the influence of season will be brought prominently to view by comparing the produce of the best and the worst seasons of the forty, and comparing the characters of the seasons themselves.

Tables 25 and 26 illustrate these points. Table 25 (p. 72) gives the produce of grain, the weight per bushel of the grain. the produce of straw, and the total produce (grain and straw together) of six very different conditions as to manuring, in each of the best two seasons, and in the worst season of the whole series. There is also given the deficiency of produce in the bad season compared with that in each of the two good seasons.

For wheat 1863 was the best season of the forty. For barley 1863 was also a very good year for both grain and straw; but it was not so good for such a variety of manures as were 1854 and 1857, which (in the table) are adopted as the best seasons.

For almost all conditions of manuring 1854 was the season of the highest total produce, grain and straw together; that is, it was the season of the greatest luxuriance or vegetative activity. But 1857 was, especially for the highest manuring, the one of the highest produce of grain and of the highest quality or maturity of grain, as evidenced by the weight per bushel. Thus, 1854 was the highest for luxuriance and 1857 the highest for maturation of the crop.

For wheat 1879 was decidedly the worst season of the forty. For barley, also, 1879 was a very bad season; but 1887 was worse still, especially for high manuring, and it is therefore adopted as the worst season for barley.

The plats selected for illustration are those without manure, with farmyard manure, with mixed mineral manure alone, with mixed mineral manure and ammonium salts, with mixed mineral manure and nitrate of soda, and with mixed mineral manure and rape cake.

The figures speak for themselves, and will repay careful study; but I can only refer to them very briefly here. The lower division of the table shows that, under each of the six very different conditions as to

manuring, 1854 yielded a much higher total produce (grain and straw together) than 1857. But the upper division shows that, notwithstanding there was the less amount of plant in 1857, as shown by the less amount of straw and total produce, it gave, in most cases, nearly as much grain as 1854; and in two—those with the highest nitrogenous manuring (and both years were within the first six, when the larger amounts were applied)—1857 gave more grain than 1854. The weight per bushel of the grain was also higher in 1857 on all the plats where nitrogenous manures were used.

TABLE 25.—*Produce of barley in the two best seasons, 1854 and 1857; in the worst season, 1887, and the average over forty years, 1852–1891.*

Plats.	Description of manures (quantities per acre).	Best seasons. 1854.	Best seasons. 1857.	Worst season, 1887.	1887 + or —. 1854.	1887 + or —. 1857.	Average of forty years.
	Dressed grain per acre:						
10	Unmanured ....bush..	35	26⅛	7½	—27½	—18⅝	16½
7-2	Farmyard manure ....do...	56⅜	51¼	26	—30⅜	—25¼	48⅝
40	Mixed mineral manure alone....do...	42	39¾	8⅝	—33⅜	—31⅛	22⅜
4A	Mixed mineral manure and 200 pounds ammonium salts = 43 pounds N ....bush..	60⅝	57⅜	22⅝	—38	—34¾	43½
4AA	Mixed mineral manure and 275 pounds sodium nitrate = 43 pounds N. bush..	62¾	64⅞	25½	—37¼	—39⅜	45½
4C	Mixed mineral manure and 1,000 pounds rape cake = 49 pounds N.......................... bush..	60¼	62¼	21	—39¼	—41¼	43¼
	Weight per bushel of dressed grain:						
10	Unmanured ....lbs..	53.6	52	51	—2.6	—1	52
7-2	Farmyard manure ....do...	53.9	54.2	55.3	+1.4	+1.1	54.3
40	Mixed mineral manure alone...do...	54	53.7	51.8	—2.2	—1.9	53
4A	Mixed mineral manure and 200 pounds ammonium salts = 43 pounds N. lbs..	54.3	54.8	53.3	—1	—1.5	54.1
4AA	Mixed mineral manure and 275 pounds sodium nitrate = 43 pounds N. lbs..	52.1	53.9	53.7	+1.6	— .2	53.7
4C	Mixed mineral manure and 1,000 pounds rape cake = 49 pounds N ....lbs..	52.8	54.1	53.4	+ .6	— .7	53.9
	Straw per acre:						
10	Unmanured ....lbs..	2,442	1,425	648	—1,794	— 777	1,044
7-2	Farmyard manure ....do...	4,171	2,649	1,842	—2,329	— 807	3,247
40	Mixed mineral manure, alone ...do...	2,595	1,920	630	—1,965	—1,290	1,279
4A	Mixed mineral manure and 200 pounds ammonium salts = 43 pounds N. lbs..	4,530	3,120	1,705	—2,825	—1,415	2,904
4AA	Mixed mineral manure and 275 pounds sodium nitrate = 43 pounds N. lbs..	5,487	4,057	2,073	—3,414	—1,984	3,186
4C	Mixed mineral manure and 1,000 pounds rape cake = 49 pounds N ....lbs..	4,712	3,705	1,740	—2,972	—1,965	2,875
	Total produce (grain and straw) per acre:						
10	Unmanured....................lbs..	4,405	2,878	1,043	—3,362	—1,835	1,976
7-2	Farmyard manure..............do...	7,298	5,564	3,294	—4,004	—2,270	6,015
40	Mixed mineral manure alone ...do...	4,969	4,111	1,088	—3,881	—3,023	2,530
4A	Mixed mineral manure and 200 pounds ammonium salts = 43 pounds N. lbs..	7,958	6,336	2,929	—5,029	—3,407	5,365
4AA	Mixed mineral manure and 275 pounds sodium nitrate = 43 pounds N. lbs..	9,026	7,734	3,455	—5,571	—4,279	5,761
4C	Mixed mineral manure and 1,000 pounds rape cake = 49 pounds N ....lbs	8,125	7,241	2,875	—5,250	—4,366	5,319

NOTE.—Plat 4AA, ammonium salts = 86 pounds nitrogen first six years, = 43 pounds next ten years; sodium nitrate = 43 pounds nitrogen last twenty-four years. Plat 4C, 2,000 pounds rape cake first six years; 1,000 pounds since.

The contrast between the produce in these two very different good years and that in the worst season, 1887, is very striking. In fact, the difference amounted in several cases to more than the average crop of the country.

For comparison with the produce of these selected years the average on each of the six plats over the forty years is given. It will be seen

how very much higher than the average is the produce in the good years and how very much lower it is in the bad season. Indeed, it is in the bad season generally only about or less than half as much as the average.

It will be of interest to consider, however briefly, some of the climatic characteristics of these various seasons.

The next table (26) shows, for each month of each of the three seasons, reckoning from October in the preceding year to September in the year of growth, the mean temperature and the rainfall above or below the average.

TABLE 26.—*Character of the two best seasons, 1854 and 1857, and of the worst season, 1887, temperature and rainfall + or — average.*

Month.	Mean temperature.			Rainfall.			Days of rain 0.01 inch or more.		
	Best two.		Worst.	Best two.		Worst.	Best two.		Worst.
	1853–54.	1856–57.	1886–87.	1853–54.	1856–57.	1886–87.	1853–54.	1856–57.	1886–87.
	Deg. F.	*Deg. F.*	*Deg. F.*	*Inches.*	*Inches.*	*Inches.*	*Days.*	*Days.*	*Days.*
October	+1.3	+2.1	+3.7	+1.43	—0.89	—1.39	+13	— 4	0
November	— .2	—1.6	+1.7	— .45	—1.15	+ .62	— 2	— 3	+2
December	—5.2	+1	—2.7	—1.30	— .27	+1.50	0	+ 1	+6
January	+2.4	.0	—1	— .60	+ .60	— .85	+ 3	+ 7	+2
February	+ .8	+ .5	+ .2	— .29	—1.30	— .97	— 3	— 8	—7
March	+2.7	+ .7	—3.5	—1.28	— .77	— .25	— 6	— 2	—2
April	+2.3	— .4	—2	—1.11	— .30	+ .05	— 4	+ 7	0
May	—1.6	+1.5	—2.7	+1.51	—1.67	— .28	+ 5	— 6	+7
June	—2.3	+3.8	+2.7	— .99	+ .80	— .67	+ 1	— 2	—8
July	—1.3	+2.9	+4.9	— .85	—1.50	—1.31	+ 4	— 2	—1
August	.0	+4.9	+1.6	+ .21	+ .10	— .05	+ 1	0	—2
September	+1.6	+3.2	—2.5	—1.42	+1	— .19	— 3	+ 1	+4
Average	....	+1.5	....	....	....	....	....	....	....
Total	....	....	....	—5.14	—5.35	—3.79	+ 9	—11	+1

It is obvious that different seasons will differ almost infinitely at each succeeding period of their advance, and that with each variation the character of development of the plant will also vary, tending to luxuriance or to maturation, that is, to quantity or to quality as the case may be. Hence, only a very detailed consideration of climatic statistics, taken together with careful periodic observations in the field, can afford a really clear perception of the connection between the ever-fluctuating characters of season and the equally fluctuating characters of growth and produce. It is, in fact, the distribution of the various elements making up the season, their mutual adaptations, and their adaptation to the stage of growth of the plant which throughout influence the tendency to produce quantity or quality. Still it will be seen that the limited summary of the meteorological conditions of the seasons in question, which can alone be given here, is not without significance. First, then, as to 1854, the season of great luxuriance and high total produce. The table shows that there was an excess of temperature in January, February, March, and April, with a deficiency of rain from November (1853) to April, inclusive; but that during May, June, and July, that is, the months of active above-ground growth, there were lower than the average temperatures, with a considerable excess of rain in May, and then a deficiency—conditions obviously favoring

continued vegetation and slow maturation. For the crop of 1857 there was less excess of temperature and less than the average amount of rain to the end of April; then, from May to August inclusive, there was both considerable excess of temperature and considerable deficiency of rain; that is, there were throughout the period of active above-ground growth conditions favoring seeding tendency and maturation rather than luxuriance. Thus, then, the two good seasons were very different in their climatic characteristics as they were in the character of their produce.

Compared with these, it may be mentioned that the very bad season of 1879 was characterized by much lower than average temperatures throughout the winter, spring, and summer, with, at the same time, great excess of rain from January to September inclusive, the result being amounts of produce greatly below the average and very low weight per bushel of the grain. The season of 1887, on the other hand, which gave even lower amounts of produce than 1879, especially with high manuring, and which is adopted as the "worst" season, was in some important respects very different in character. Thus, while the crop of 1879 failed from low temperatures combined with excess of rain throughout, the season of 1887 was characterized by low temperatures, especially in March, April, and May, but associated with a deficiency of rain, commencing in January. The result was very restricted spring growth. In June and July, however, the temperature was considerably in excess of the average, but with continued and considerable deficiency of rain, the combination further restricting growth and bringing on premature ripening.

INFLUENCE OF EXHAUSTION, MANURES, AND VARIATIONS OF SEASON ON THE COMPOSITION OF THE BARLEY CROP.

In the case of wheat it was found that the supplies within the soil, both of nitrogen and of mineral constituents, had a very direct influence on the composition of the crop so long as it was only in the vegetative stage, but that there was, nevertheless, very great uniformity in the composition of the final product of the plant—the seed—provided only that it was perfectly matured. The composition of the straw, however, showed a very direct connection with the supplies by the soil. The composition of the grain was, on the other hand, materially influenced by variations of season. But variations of season obviously have great influence on the condition of maturation, while difference in maturation implies difference in organic composition—the amount of carbohydrates (starch especially) formed. In fact, such variations in composition imply deviations from perfect and normal maturation, and such deviations are associated not only with differences in the organic composition—the relation of the nitrogenous to the non-nitrogenous constituents—but with differences in the mineral composition also. It follows that variations in the composition of the final

and very definite product, the seed, should be much more clearly traceable to variations of season than to variations in the supplies within the soil; that is, than to exhaustion or manures. This was found to be very strikingly so in the case of wheat, and we have now to consider how far it is so with its near ally, barley.

The results given in Table 27 forcibly illustrate the much greater influence of variations of season than of manures on the composition of barley grain. Many complete analyses of the ash of the grain (and also the straw) grown by different manures and in different seasons have been made, and taking for illustration the important and characteristic constituents, potash and phosphoric acid, the table shows, for three very different manurial conditions, the highest, the lowest, and the mean amounts of potash and phosphoric acid in 1,000 parts of the dry substance of the grain and of the straw in different seasons. The manurial conditions selected are: (1) Without manure, (2) with farmyard manure, (3) mixed mineral manure (including potash) and ammonium salts.

TABLE 27.—*Highest, lowest, and mean amounts of potash and phosphoric acid, per 1,000 dry substance.*

Plat.		Per 1,000 dry grain.					Per 1,000 dry straw.				
		Highest.		Lowest.		Mean.	Highest.		Lowest.		Mean.
	Potash:										
1 O	Unmanured	1871	7.66	1853	6	6.54	1871	11.77	1856	5.25	8.55
7-2	Farmyard manure	1871	8.36	1856	5.89	6.81	1871	22.01	1856	6.76	13.23
4 A	Mixed mineral manure and ammonium salts.	1871	7.98	1852	5.62	6.61	1871	22.53	1852	5.67	14.05
	Phosphoric acid:										
1 O	Unmanured	1852	10.08	1854	8.85	9.27	1856	2.60	1863	1.20	1.74
7-2	Farmyard manure	1871	10.50	1854	9.23	9.99	1856	2.92	1863	1.48	2.19
4 A	Mixed mineral manure and ammonium salts.	1856	10.39	1863	8.84	9.58	1856	3.12	1863	1.06	1.94

First, as to the amounts of potash in 1,000 parts dry substance of the grain of the differently manured plats in the different seasons. It is seen that there is much greater variation in the proportion of the potash in the different seasons with the same manure than there is with the different manures. Further, the seasons showing the highest amount of potash were of much higher maturing character than those showing the lowest amounts. Next, it is seen that there is still greater, indeed enormous, variation in the amount of potash in the dry substance of the straw with the same manure in different seasons. There is also great variation according to manure; comparatively little when there was full supply, but considerable without manure—that is, with exhaustion. Turning now to the phosphoric acid in the grain, there is here again much more variation in different seasons with the same manure than with the different manures. But, while in the case of potash there is the higher proportion in the better seasons, in that of phosporic acid there are lower amounts in the dry substance in the better seasons. In fact, high amount of potash in the ash and in the dry

substance of the grain is, as a rule, associated with high maturation—that is, with high proportion of starch—while high proportion of phosphoric acid is generally associated with low maturation and with high proportion of nitrogen. The proportion of phosphoric acid in the straw also varies more with season than with manure, and it is the highest in the worst seasons.

The connection between maturation and composition is further illustrated by the results in Table 28, which shows the general characters of the produce as indicated by the weight per bushel of the grain of four very different seasons so far as the maturation of the grain was concerned. The table further shows the percentage of ash (pure) in the dry matter of the grain and of the straw; the percentage of potash and of phosphoric acid in the ash of the grain and of the straw; also the potash and phosphoric acid per 1,000 dry matter of grain and of straw, the results being the means of six differently manured plats in each season. Lastly, the seasons are arranged in the order of highest weight per bushel of grain, this being, upon the whole, the best practical measure of high quality, or at least of high maturation.

TABLE 28.—*Weight of grain, as related to ash, potash, and phosphoric acid.*

Harvests.	Weight per bushel of grain.	Ash (pure) in dry matter.	Ash (pure).		Per 1,000 dry matter.	
			Potash.	Phosphoric acid.	Potash.	Phosphoric acid.
Grain:	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*		
1871	55.9	2.65	29.80	35.33	7.89	9.39
1863	55.3	2.55	26.59	35.80	6.78	9.15
1852	51.7	2.48	23.84	40.89	5.90	10.13
1856	47.4	2.44	24.21	41.35	5.89	10.09
Straw:						
1871	55.9	6.27	26.01	3.68	16.57	2.31
1863	55.3	5.48	24.91	2.29	13.99	1.26
1852	51.7	4.45	14.62	4.05	6.58	1.81
1856	47.4	4.49	13.51	6.42	6.10	2.89

It will be seen that the average weight per bushel of the grain was, in 1871, 55.9 pounds; in 1863, 55.3 pounds; in 1852, 51.7 pounds, and in 1856 only 47.4 pounds, or about 8 pounds less than in the two seasons of highest weight. There is here, then, very great variation in the character of these four seasons and in the degree of maturation of the grain accordingly. No determinations of nitrogen are available, but it may be stated that the percentage of nitrogen is almost uniformly lower in the seasons of high maturation. Turning to the particulars of composition given in the table for each of the four seasons, it is seen that in both grain and straw there is a higher percentage of ash in the dry substance the higher the quality of the grain. There are also higher percentages of potash but lower percentages of phosphoric acid, both in the ash and in the dry substance, the higher the quality of the grain. In wheat, however, there is lower, not higher, percentage of ash in the dry substance of the grain the higher its quality. But in wheat, as in barley, there is higher percentage of

potash and lower percentage of phosphoric acid in the ash the higher the quality. On the other hand, there is not, in the case of wheat, as there is in that of barley, a much higher percentage of potash in the dry substance the higher the quality. This difference may be partly due to the larger proportion of starch to nitrogenous substance in the barley, but it is probably in part also due to the paleæ (or chaff) of the barley, but not of the wheat, being adherent, and retaining the surplus potash brought up for grain formation.

In both descriptions of grain there is very uniformly a lower proportion of phosphoric acid in the dry matter the higher the quality of the grain.

In the straw there is high percentage of ash in the dry matter, high percentage of potash, and low percentage of phosphoric acid in the ash and in the dry matter the higher the quality of the grain. In the straw, however, the variations show a much wider range, indicating much less definiteness and greater irregularity in condition. Thus, then, the higher the quality of the barley grain—that is, the higher its proportion of starch—the higher is the proportion of potash and the lower is that of phosphoric acid. Though not shown in the table, it may be mentioned that with a higher proportion of potash there is generally a lower proportion of both lime and magnesia, and with a lower proportion of phosphoric acid there is a somewhat higher proportion of sulphuric acid.

Another point of interest is, although it is true the amounts are small, that there is a tendency to a higher proportion of soda in the grain ash and in the dry matter of the grain in the better seasons, even when there is no deficiency of potash. This, again, is probably due to the ash of the barley grain containing that of the adherent paleæ.

In relation to the composition of the straw, the most striking result is (though not shown in the table) that there is little more than two-thirds as high a percentage of silica in the ash of the produce of the better as in that of the worse seasons.

The results in Table 29 (p. 78) illustrate the influence of exhaustion and of full supply of mineral or ash constituents on the mineral composition of the produce, both grain and straw. They relate to the mineral composition of the produce grown for forty years in succession: (1) By ammonium salts and superphosphate, (2) by ammonium salts, superphosphate and potash, soda, and magnesia in addition. There are given results obtained by complete analyses of the ash of samples mixed in proportion to the amount of the produce (grain and straw separately) each year for the four ten-year periods, 1852–1861, 1862–1871, 1872–1881, and 1882–1891. The upper division of the table gives for the potash, the second for the soda, the third for the phosphoric acid, and the fourth for the silica: (1) The percentage in the ash (pure) of the grain and of the straw, (2) the amounts per 1,000 dry matter of grain and of straw, (3) the amounts per acre per annum, pounds, in the grain, in the straw, and in the total produce (grain and straw together).

TABLE 29.—*Experiments on barley, Hoosfield, Rothamsted—Potash, soda, phosphoric acid, and silica (per cent in ash, per 1,000 dry substance, and quantities per acre).*

	Per cent in ash.				Per 1,000 dry matter.				Pounds per acre per annum.					
	Grain.		Straw.		Grain.		Straw.		In grain.		In straw.		In total produce.	
	Ammonium salts=43 pounds nitrogen and superphosphate—													
	Without potash.	With potash.	Without potash.	With potash.	Without potash.	With potash.	Without potash.	With potash.	Without potash.	With potash.	Without potash.	With potash.	Without potash.	With potash.
	2a	*4a*	*2a*	*4a*	*2a*	*4a*	*2a*	*4a*	*2a*	*4a*	*2a*	*4a*	*2a*	*4a*
POTASH.														
10 years, 1852–61	26.79	27.62	18.44	27.85	6.22	6.52	8.54	14.65	13.1	13.8	22.5	39.9	35.6	53.7
10 years, 1862–71	25.97	28.46	13.31	32.92	6.23	6.82	6.41	18.51	14.5	15.3	16.4	48.4	30.9	63.7
10 years, 1872–81	25.68	28.85	9.72	33.64	6.02	6.99	4.41	18.10	11.5	13.7	8	37.8	19.5	51.5
10 years, 1882–91	25.35	28.67	7.36	29.72	5.85	6.90	3.38	15.25	9.7	12.8	6	32	15.7	44.8
40 years, 1852–91	25.95	28.40	12.21	31.03	6.08	6.81	5.69	16.63	12.2	13.9	13.2	39.5	25.4	53.4
SODA.														
10 years, 1852–61	1.15	.51	6.42	2.50	.27	.12	2.97	1.32	.6	.2	7.8	3.6	8.4	3.8
10 years, 1862–71	2.07	.58	11.39	2.30	.50	.14	5.49	1.29	1.1	.3	14.1	3.4	15.2	3.7
10 years, 1872–81	2.83	.77	12.69	2.09	.66	.18	5.75	1.13	1.3	.4	10.5	2.3	11.8	2.7
10 years, 1882–91	2.94	.44	11.85	1.85	.68	.11	5.44	.95	1.1	.2	9.6	2	10.7	2.2
40 years, 1852–91	2.25	.58	10.59	2.19	.53	.14	4.91	1.17	1	.3	10.5	2.8	11.5	3.1
PHOSPHORIC ACID.														
10 years, 1852–61	38.55	38.53	3.06	2.97	8.95	9.10	1.42	1.56	18.8	19.2	3.7	4.3	22.5	23.5
10 years, 1862–71	36.36	37.31	2.55	2.47	8.72	8.95	1.23	1.39	20.2	20.1	3.2	3.6	23.4	23.7
10 years, 1872–81	37.65	38.36	3.33	2.91	8.82	9.29	1.51	1.57	16.9	18.1	2.8	3.3	19.7	21.4
10 years, 1882–91	38.25	39.56	3.76	3.30	8.82	9.52	1.73	1.69	14.7	17.7	3.1	3.6	17.8	21.3
40 years, 1852–91	37.70	38.44	3.18	2.91	8.83	9.22	1.47	1.55	17.6	18.8	3.2	3.7	20.8	22.5
SILICA.														
10 years, 1852–61	18.60	18.67	47.87	43.67	4.32	4.41	22.16	22.98	9.1	9.3	58.5	62.6	67.6	71.9
10 years, 1862–71	20.62	19.18	43.39	35.41	4.95	4.60	20.92	19.91	11.5	10.3	53.6	52.1	65.1	62.4
10 years, 1872–81	18.50	17.47	43.73	34.09	4.34	4.23	19.82	18.34	8.3	8.3	36.3	38.3	44.6	46.6
10 years, 1882–91	18.36	16.73	46.09	37.16	4.24	4.03	21.16	19.06	7.1	7.5	37.5	40	44.6	47.5
40 years, 1852–91	19.02	18.01	45.27	37.58	4.46	4.32	21.02	20.07	9	8.9	46.5	48.2	55.5	57.1

First, referring to the potash, its percentage, even in the grain ash, is seen somewhat to diminish from period to period where none was supplied in manure, and somewhat to increase where there was an annual supply of it by manure. In the straw ash, however, the per centage of potash went down from 18.44 over the first period to only 7.36, or less than half over the fourth, where none was supplied; but it increased from 27.85 per cent over the first to 33.64 over the third, but to only 29.72 over the fourth period, where it was annually supplied. Thus the influence of exhaustion or of full supply of potash has been comparatively small on the mineral composition of the grain, but very great on that of the straw.

The point is further illustrated in the next results, which show the amounts of potash per 1,000 dry matter of grain and of straw, respectively. There is, again, comparatively little variation in the relation

of the potash to the organic matter in the case of the grain, but very great variation in that of the straw, accordingly as there is exhaustion or full supply. When it is borne in mind that the ash of barley grain contains that of the adherent paleæ, as well as that of the grain proper, the conclusion is that the variation in the proportion of potash to the fixed organic substance of the grain itself is much less than the figures would indicate. It is probable that the variation. such as it is, is associated with a different relative proportion of the organic compounds themselves—of the fully matured nonnitrogenous to the nitrogenous bodies. In fact, the evidence, duly considered, is not in favor of the view that there is variation in the proportion of the potash to the fixed and ripened nonnitrogenous constituents, with the formation of which it is probably to a great extent associated.

The effects of exhaustion, or of full supply of constituents, are still more strikingly brought out by a study of the figures showing the amounts of potash taken up and retained per acre, by the above-ground growth without and with the supply of it. Thus the average amounts of potash per acre per annum in the entire crop (grain and straw together) were, over the four successive periods without supply of it. 35.6, 30.9, 19.5, and 15.7 pounds, and with full supply they were, over the same periods, 53.7, 63.7, 51.5, and 44.8 pounds. That is to say, there was without supply less than half as much potash annually stored up in the crop over the last as over the first ten years of the forty. On the other hand, with full supply there was over the second period more than, and over the third about the same amount as, over the first period. but there was less over the fourth. Further, there was over the first period about one and a half times, over the second more than twice, over the third more than two and a half. and over the fourth, nearly three times as much potash in the total crop with as without supply. Lastly, over the forty years there was without supply of potash an average of only 25.4 pounds, but with it 53.4 pounds of potash per acre per annum in the crop. Yet, with these enormous differences in the amounts taken up and retained by the entire above-ground growth in the different cases, there was proportionally very much less difference in the amounts accumulated in the grain. Thus. over the first period the amounts in the grain were, over the first period, without supply 13.1 pounds, and with it 13.8 pounds; over the second, without supply 14.5 pounds, and with it 15.3 pounds; over the third, without supply 11.5 pounds, and with supply 13.7 pounds, and over the fourth period, without supply 9.7 pounds and with supply 12.8 pounds. Lastly, over the total period of forty years the amounts were without supply 12.2 pounds and with supply 13.9 pounds. It is thus seen that over each period there was rather less in the grain without than with supply, but that the deficiency was not material until the third period, that is, until after twenty years without supply in the one case and twenty years with it in the other. In reference to

these results it will be of interest to consider what were the actual amounts of produce—grain, straw, and total—on each of the two plats, over the successive ten yearly periods, and over the forty years. The following table (30) gives particulars on these points:

TABLE 30.—*Amount of dressed grain, straw, and total produce.*

	Dressed grain.		Straw.		Total produce.	
	Ammonium salts=43 pounds nitrogen and superphosphate—					
	Without potash.	With potash.	Without potash.	With potash.	Without potash.	With potash.
	2*a*	4*a*	2*a*	4*a*	2*a*	4*a*
	Bushels.	*Bushels.*	*Cwt.*	*Cwt.*	*Pounds.*	*Pounds.*
10 years, 1852–61	$45\frac{5}{8}$	$46\frac{1}{8}$	$27\frac{7}{8}$	$28\frac{7}{8}$	5, 683	5, 827
10 years, 1862–71	$48\frac{3}{8}$	$46\frac{3}{8}$	$27\frac{1}{2}$	28	5, 837	5, 808
10 years, 1872–81	$40\frac{1}{2}$	$40\frac{3}{4}$	$20\frac{1}{2}$	$23\frac{1}{2}$	4, 584	4, 969
10 years, 1882–91	$36\frac{5}{8}$	$40\frac{3}{4}$	$19\frac{3}{4}$	$23\frac{3}{8}$	4, 218	4, 854
40 years 1852–91	$42\frac{3}{4}$	$43\frac{1}{2}$	$23\frac{7}{8}$	$25\frac{7}{8}$	5, 081	5, 364

It will be seen that there was almost identically the same amount of produce of grain per acre per annum, over the forty years, without as with the supply of potash, the average annual deficiency being only three-fourths of a bushel, and the details show that the falling off was chiefly during the fourth period of ten years. There was, however, some deficiency of straw without potash supply over each of the four periods. It was considerable over the third and fourth periods, and it amounted to an average of 2 cwt. per acre per annum over the forty years. It would appear, therefore, that the diminished amount of potash taken up by the plant where it was not supplied was sufficient for the exigencies of grain formation for the greater part of the whole period, and that at least a large proportion of the excess taken up where it was liberally supplied was surplusage, so far as the requirements of the grain were concerned. Some idea of how great was this surplusage may be formed by reference to the difference in the amounts of potash eventually remaining in the straw. Thus the average amounts of potash per acre per annum in the straw were: Over the first period, without supply 22.5 pounds, and with it 39.9 pounds, or +17.4 pounds; over the second period, without supply 16.4 pounds, and with it 48.4 pounds, or +32.0 pounds; over the third period, without supply 8.0 pounds, and with it 37.8 pounds, or +29.8 pounds; over the fourth period, without supply 6 pounds, and with it 32 pounds, or +26 pounds; and over the forty years, without supply 13.2 pounds, and with it 39.5 pounds, or 26.3 pounds per acre per annum more with than without supply. It is not to be supposed, however, that the whole of these plus amounts was surplusage; for, although the average yield of grain has been to such a great extent maintained, the character of the plant has obviously depreciated for a good many years, and several times in recent seasons even the yield of grain has

been considerably deficient. Indeed, it would seem that the plant has become more and more sensitive to adverse conditions of soil and season.

Turning now to the soda, it is seen that, whether we look at its percentage in the ash of the grain and of the straw, its proportion in 1,000 dry substance, or the amounts in the acreage crops, very much more was found in the crops grown without its supply, but where potash was deficient, than where soda was itself annually supplied. This is strikingly illustrated by reference to the average amounts per acre per annum in the total crops, grain and straw together. Thus the average amounts of soda in the total crop were, over the first period, without any supply of either potash, soda, or magnesia, 8.4 pounds, and with the supply of all three only 3.8 pounds; over the second period, without the supply 15.2 pounds, and with it only 3.7 pounds; over the third period, without the supply 11.8 pounds, and with it only 2.7 pounds; over the fourth period, without the supply 10.7 pounds, and with it only 2.2 pounds; and lastly, over the 40 years, without supply of either potash, soda, or magnesia, 11.5 pounds of soda, and with the supply of all three only 3.1 pounds of soda per acre per annum. Thus, then, not only was there much more soda taken up or retained by the plant where it was not supplied than where it was, but it is evident that there was the more soda taken up the less the supply of potash. The amounts of soda retained in the grain are, however, seen to be but small; there was more, it is true, where there was a deficiency of potash and where more soda was taken up. But, looking to the amounts of soda per cent in the grain ash, or per 1,000 dry substance of the grain, it would seem probable that the larger amounts where there was a deficiency of potash and more total soda taken up were only due to larger amounts eliminated from the grain proper, and retained in the adherent paleæ, or chaff. Whether, however, the soda has been of any avail in the earlier or merely vegetative stages of growth, as a carrier, or otherwise, may be a question.

Next, as to the phosphoric acid, of which there was the same annual supply on both plats. It is seen that, whether we take its percentage in the ash, its proportion to the dry substance, or its average quantity per acre, the amounts are, in the comparable cases, comparatively uniform, the differences not being greater than can be supposed to be connected with the differences in growth due to the differences in the supply of other constituents.

Lastly, as to silica, the chief point of interest to remark is, that, as the figures show, its percentage in these barley-grain ashes ranges from under 17 to more than 20, where, as in wheat-grain ash, it ranges only from about 0.5 to about 1.5 per cent; or, if we take the proportion of silica to 1,000 dry substance of grain, in barley it ranges from 4 to 5 parts, and in wheat only from about 0.1 to about 0.3 parts. This difference is obviously due to the chaff being adherent in the case of barley and

not in that of wheat, and the figures afford clear illustration of the material degree in which the composition of barley-grain ash is influenced by the inclusion in it of what is, in a sense, extraneous matter. It is indeed obvious that, under such circumstances, we should expect, as we find, less definiteness in the mineral composition of the grain of barley than in that of wheat.

In reference to the foregoing results showing the influence of exhaustion and of supply of certain mineral constituents within the soil on the mineral composition of the produce grown, it is obviously of interest to consider, as far as existing evidence will permit, the amount and the condition of availability, especially of the potash and the phosphoric acid, within the soil. Unfortunately results obtained by the generally adopted methods of soil analysis do not enable us to discriminate between the total and the immediately or approximately available constituents. The difficulty was recognized and pointed out at Rothamsted very early in the course of our investigations. From time to time the subject has also been discussed by others, and in recent years several experimenters have approached it from various points of view, with the object of fixing upon some useful modification of method. More than twenty years ago Hermann von Liebig, having asked for samples of some of the plats of the Rothamsted experimental wheat field, samples from five plats, to three depths of 9 inches each in each case, were supplied to him. He determined in them, besides other constituents, the potash and the phosphoric acid, the former in a dilute acetic acid extract and the latter in a dilute nitric acid extract. The results unmistakably showed differences in the amounts of potash and phosphoric acid in the soils, according to the manures employed. They further brought out the interesting fact that comparatively very little of the applied potash or phosphoric acid had gone below the first 9 inches of soil, and that certainly none had gone into the third depth.

In our own country, for some years past, Dr. Bernard Dyer has been investigating the subject of "The analytical determination of probably available 'mineral' plant food in soils"[1] and, at the suggestion of Professor Armstrong, one of the Rothamsted trust committee, he asked whether we could supply him, for the purposes of his investigation, with samples of soils from some of the experimental fields at Rothamsted, of which the manure and crop history was known. Accordingly, in 1889, we gave him facilities for taking samples of the surface soil, to a depth of 9 inches, from 22 of the plats in the experimental barley field, and we also provided him with samples which had been collected in 1882, from a few selected plats, to the depth of three times 9 inches.

In all these samples Dr. Dyer has determined the total potash, by acid, fusion, etc., the amount dissolved by hydrochloric acid, and the amount taken up by a 1 per cent citric acid solution; also the amounts

[1] Trans. Chem. Soc. 1894, p. 115. See also the discussion on his paper, Proc. Chem. Soc., No. 134 (1893–94), p. 37. (Experiment Station Record, 5, p. 1013.)

of phosphoric acid, by hydrochloric acid, and by a 1 per cent solution of citric acid. Dr. Dyer's results, obtained on the surface soils of the series of 22 plats, show at a glance comparative exhaustion or accumulation of both potash and phosphoric acid, whether hydrochloric acid or the dilute citric acid solution was used. There are, indeed, among these numerous results, some apparently inconsistent quantitative indications, but these are probably attributable to irregularities in the soils themselves, and therefore to the difficulties of sampling rather than to those of analysis.

It will be useful to refer a little more in detail to the results obtained on the soils of plat *2a* and plat *4a*, the manure and crop history of which has been pretty fully illustrated by the results given in Tables 29 and 30 and the discussion of them. It would appear that not more than two-thirds of the potash estimated to be accumulated where it was supplied was taken up by hydrochloric acid, but that approximately the whole of the accumulated phosphoric acid was so taken up. Hence, it may be judged that much of the residue of the supplied potash had gone into more fixed combinations within the soil than was the case with the phosphoric acid. Then, as to the citric acid results, it may be observed that they are so far accordant that the sample of the surface soil of the potash-exhausted plat taken in 1882 showed more potash than that taken in 1889, when the exhaustion was, of course, greater. Again, the citric acid determinations on the soil with potash supply showed more so taken up from the 1889 than from the 1882 sample, the accumulation having been the greater at the later date. It is also of interest to observe that the amounts determined in the potash-exhausted soil, by the 1 per cent citric acid solution, were about from three to five times as much as the crops would annually take up, which is a fairly consistent relation.

Further, with reference to these barley-soil results, as superphosphate was applied to both plats, the comparison of the amounts taken up on the two is of less interest than in the case of the potash, but comparison with the results obtained on another plat, otherwise similarly manured, but without superphosphate, shows, as already referred to, that the estimated accumulation of phosphoric acid was approximately indicated by the amount taken up by hydrochloric acid. The results relating to the two plats are, however, of special interest as illustrating in the one case actual exhaustion and in the other actual accumulation of potash, there being in the one a loss over the forty years of about 1,018 pounds of the potash of the soil, and in the other a gain from supply of about 3,180 pounds, while of the latter amount the results show that hydrochloric acid extracted nearly two-thirds and citric acid less than one-fourth. It is further of interest to note that Dr. Bernard Dyer's results obtained on the 1882 samples from the two plats, in each case to the depth of three times 9 inches, agree with those formerly obtained by Hermann von Liebig on the wheat-field soils, in

showing that little, if any, of either the potash or phosphoric acid artificially supplied had gone below the first 9 inches of depth.

Dr. Dyer is also working on the soils of some of the plats of the experimental wheat field, and these will afford some striking illustrations in regard to the condition of availability of accumulated residue of potash supply over a long series of years. Thus, there is a series of plats which have received the same amount of ammonium salts and superphosphate each year for forty years to 1891, inclusive, one of which has received no potash, either during those forty years or during the eight preceding years; two received potash during the first eight years, but none since, and one, besides receiving potash during the first eight years, has received it each year since. The complete manure and crop history of each of the four plats is, so far as potash and phosphoric acid are concerned, available for each of the four ten-yearly periods of the forty years, as in the case of plats 2*a* and 4*a* in the barley field. The amount and composition of the crops show great reduction in produce and exhaustion of potash where none had been applied from the beginning, less reduction and less exhaustion where there was a residue of potash from the applications during the first eight years, and, lastly, maintenance of produce and great accumulation of potash in the crops where potash has been annually applied. Further, the indication is that the whole of the residue of potash supplied during the first eight years on the plats where none has been applied since has been approximately exhausted during the succeeding forty years. It is obvious, therefore, that Dr. Dyer will find new points of interest in the investigation of the experimental wheat-field soils, for the results will afford illustrations, not only of mere exhaustion and accumulation, but of effective residue as well.

ON WHAT DOES STRENGTH OF STRAW DEPEND?

It will be appropriate to refer here to the bearing of experimental evidence on the question whether, as is frequently stated, strength of straw is dependent on a high percentage of silica. Table 31 (p. 85) affords illustrations on this point. The upper division of the table gives results relating to wheat, and the lower corresponding results relating to barley. In the case of wheat five, and in that of barley three, very different conditions of manuring are selected for illustration, and for each condition as to manuring, results obtained in bad and in good seasons are given. The particulars indicating the character of the crops are, the percentage of grain in the total produce and the weight per bushel of the dressed grain, and side by side with these are recorded the percentage of ash in the dry matter of the straw, the percentage of silica in the ash, and the percentage of silica in the dry matter.

TABLE 31.—*Per cent of silica in straw of wheat and barley, as related to grain produced.*

	Grain in total produce.	Weight per bushel of dressed grain.	Ash in dry matter.	Silica in ash.	Silica in dry matter.
WHEAT.	*Per cent.*	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
Without manure:					
1856	36.4	54.3	5.5	71.47	3.93
1858	40.6	60.4	4.9	65.85	3.23
Ammonium salts alone:					
1856	34.8	55.5	3.9	66.23	2.58
1858	40.3	59.6	4	57.47	2.30
Mixed mineral manure:					
1856	36.7	56.4	5.7	68.74	3.92
1858	43.6	61.5	5.6	64.67	3.62
Mineral manure and ammonium salts:					
1856	33.6	58	4.9	64.63	3.17
1858	38.2	62.2	5	55.60	2.78
Farmyard manure:					
1856	34.5	58.6	6.7	69.56	4.66
1858	39.6	62.6	6.54	59.71	3.90
BARLEY.					
Rape cake:					
1852	44.3	51.7	4.75	57.49	2.73
1871	45.4	56.3	5.54	42.04	2.33
Rape cake:					
1856	39.1	46.1	4.63	49.39	2.29
1863	48.4	56.3	5.17	45.62	2.36
Mineral manure and ammonium salts:					
1852	43.2	51.4	4.19	62.21	2.61
1871	43.3	56.5	6.70	32.71	2.19
Mineral manure and ammonium salts:					
1856	40.2	46.4	5.48	57.47	3.15
1863	47.3	56.5	6.32	35.24	2.23
Farmyard manure:					
1852	47	52.8	5.15	57.38	2.96
1871	43.8	56.6	7.55	42.71	3.22
Farmyard manure:					
1856	42.8	47.1	4.92	57.85	2.85
1863	48.3	57.2	6.21	43.08	2.68

In the wheat in every case and in the barley in every case but one there is a higher proportion of grain in the better season, and in every case of both wheat and barley there is a much higher weight per bushel of grain in the better season. These conditions are, in fact, proof of the superiority of the crops in the main characters of seed-forming tendency and ripening.

The percentage of ash in the dry matter of the straw is not a very significant character, and it is seen that in the case of the wheat it was on the average somewhat the lower, but in that of the barley uniformly the higher in the better seasons. The percentage of silica in the ash of the straw is more significant, and in both the wheat and the barley it is, under all the conditions of manuring, much the lower in the better seasons. More significant still is the percentage of silica in the dry matter of the straw, and it is seen that with the wheat under each condition of manuring and with the barley under most conditions it is considerably lower in the better seasons. It may be observed that the exceptions in the case of the barley were where organic manure, as in rape cake and farmyard manure, was employed. Direct analytical results clearly show, therefore, that the proportion of silica is, as a rule, lower, not higher, in the straw of the better grown and better ripened crops. This result is quite inconsistent with the usually

accepted view that high quality and stiffness of straw depend on a high amount of silica. Pierre and Bretschneider have, indeed, concluded from their recent experiments that this is not the case, and at Rothamsted we have long maintained a contrary view. In fact, high proportion of silica means a relatively low proportion of organic substance produced. Nor can there be any doubt that strength of straw depends on the favorable development of the woody substance, and the more this is attained the more will the accumulated silica be, so to speak, diluted; in other words, show a lower proportion to the organic substance.

I may mention that in our own neighborhood, where the straw-plait industry prevails, the complaint during seasons of bad harvests has been that an unusually large proportion of the straw was brittle and broke in the working, and considering the character of the seasons there can be no doubt that this was associated with low development of the woody matter and high proportion of silica.

SUMMARY AND CONCLUSIONS.

I have now illustrated the influence of exhaustion, of manures, and of variations of season on the amounts of produce and on the composition of barley.

The results have shown that on the growth of barley for more than forty years in succession on rather heavy, ordinary, arable soil, the produce by mineral manures alone was higher than that without manure; that nitrogenous manures alone gave more produce than mineral manures alone; and that mixtures of both mineral and nitrogenous manure gave much more than either used alone; indeed, generally twice or more than twice as much as mineral manures alone. Of mineral constituents, whether used alone or in mixture with nitrogenous manures, phosphates were much more effective than mixtures of salts of potash, soda, and magnesia. The averages show that under all conditions of manuring (excepting with farmyard manure) the produce was less over the later than over the earlier periods of the experiments, a result partly due to the seasons. But the average produce for the forty years of continuous growth of barley was, in all cases where nitrogenous and mineral manures (containing phosphates) were used together, much higher than the average produce of the crop grown in ordinary rotation in the United Kingdom, and very much higher than the average in most other countries when so grown.

It is seen that the requirements of barley within the soil and its susceptibility to the external influences of season are very similar to those of its near ally, wheat. There are, however, distinctions of result, dependent on differences in the habits of the two plants, and in the conditions of their cultivation accordingly.

Wheat is, with us, as a rule, sown in the autumn, on a heavier soil, and has four or five months in which to distribute its roots, and so gets possession of a wide range of soil and subsoil before barley is

sown. Barley is sown in a lighter surface soil, and with its short period for root development, relies in a much greater degree on the stores within the surface soil. Accordingly, it is more susceptible to exhaustion of surface soil as to its nitrogenous, and especially as to its mineral, supplies; and in the common practice of agriculture it is found to be more benefited by direct mineral manures, especially phosphatic manures, than is wheat when sown under equal soil conditions. The exhaustion induced by both crops is, however, characteristically that of available nitrogen; and when, under the ordinary conditions of manuring and cropping, artificial manure is still required, nitrogenous manures are, as a rule, requisite for both crops, and for the spring-sown barley superphosphate also.

Lastly, although barley is appropriately grown on lighter soils than wheat, good crops of fair quality may be grown on the heavier soils after another grain crop by the aid of artificial manures, provided that the land is sufficiently clean.

SECTION III.

EXPERIMENTS ON THE GROWTH OF VARIOUS LEGUMINOUS CROPS FOR MANY YEARS IN SUCCESSION ON THE SAME LAND; ALSO ON THE QUESTION OF THE FIXATION OF FREE NITROGEN.

INTRODUCTION.

We now come to the third element of the ordinary four-course rotation, namely, leguminous crops, which, indeed, have a place in most other rotations also.

It is found that within certain limits the requirements and the results of growth of different members of one and the same family show certain characteristics in common, while those of different families show more or less of distinctive character. Nevertheless, there are some important points of similarity, as well as of contrast, between the requirements of the agricultural representatives of the Gramineæ, the Cruciferæ, the Chenopodiaceæ, and the Solanaceæ. It will be seen, however, that the agricultural representatives of the Leguminosæ, all of which are included in the suborder Papilionaceæ, and some of which are of much importance in our agriculture, show very marked differences, as compared with those of any of the orders above enumerated. It so happens that both the scientific interest and the practical value of these crops, whether as elements in rotation or as grown in the mixed herbage of grass land, depend very largely on the amount of nitrogen which they contain, and on the sources of their nitrogen; and especially on the great differences in these respects between them and the representatives of the other orders with which they are grown, either in alternation in our rotations or in association in our meadows and pastures. So much is this the case that it is essential to a proper understanding and appreciation of the characteristics of growth of these crops, and for the illustration of their value and importance as depending on those characteristics, to compare and to contrast the conditions and results of their growth with those of the crops of other orders. I will, therefore, first briefly call attention to the difference in the amounts of nitrogen assimilated over a given area by different crops, when each is grown for many years in succession on the same land without any nitrogenous manure; that is to say, under conditions in which the soil is to a great extent exhausted of accumulations of nitrogen due to recent supplies by manure, and when, therefore, the plants have to rely largely on what may be called the natural resources of the soil, and on those of the atmosphere.

YIELD OF NITROGEN PER ACRE IN DIFFERENT CROPS.

Table 32 shows the yield of nitrogen per acre per annum, with mineral but without any nitrogenous manure, in wheat and in barley as gramineous crops, in turnips as representatives of the Cruciferæ, in sugar beet and mangel-wurzel of the Chenopodiaceæ, and in beans and clover as leguminous crops, when each is grown for many years in succession on the same land:

TABLE 32.—*Nitrogen per acre per annum in various crops grown at Rothamsted, with mineral but without nitrogenous manure.*

Duration of experiment.	Average nitrogen per acre per annum.
Wheat:	*Pounds.*
12 years, 1852–63	27
12 years, 1864–75	17.2
24 years, 1852–75	22.1
Barley:	
12 years, 1852–63	26
12 years, 1864–75	18.8
24 years, 1852–75	22.4
Root crops:	
Swedish turnips, 15 years, 1856–70[1]	18.5
Sugar beet, 5 years, 1871–75	14.7
Mangels, 10 years, 1876–85	14
Total, 30 years, 1856–85	16.4
Beans:	
12 years, 1847–58	61.5
12 years, 1859–70[2]	29.5
24 years, 1847–70	45.5
Clover:	
22 years, 1849–70[3]	39.8

[1] Thirteen years; two years failed.
[2] Nine years, beans; one year, wheat; two years, fallow.
[3] Six years, clover; one year, wheat; three years, barley; twelve years, fallow.

Incidentally it is to be noticed that in the case of each of the crops—wheat, barley, and beans—thus grown year after year on the same land for many years in succession without nitrogenous manure, there was a reduction in the yield of nitrogen per acre per annum over the second period compared with the first; that is, as the previous accumulations within the soil became reduced. Disregarding this tendency to reduced yield, it is seen that over the same period of twenty-four years, with full mineral but without nitrogenous manure, the wheat yielded an average of 22.1 pounds and the barley 22.4 pounds of nitrogen per acre per annum, the two allied crops, therefore, yielding almost identical amounts in their above-ground produce, without nitrogenous manure, on soil very poor in available nitrogen, so far as accumulations due to recent applications of nitrogenous manure are concerned.

Turning now to the yield of nitrogen in the root crops—turnips, sugar beet, and mangel-wurzel—it may be mentioned that prior to the

period referred to in the table turnips had been grown for a number of years and had yielded 42 pounds of nitrogen per acre per annum, due to the accumulations from comparatively recent nitrogenous manuring. But it is seen that after these accumulations had been reduced Swedish turnips gave over fifteen years an average of only 18.5 pounds, sugar beet over the next five years an average of only 14.7 pounds, and mangel-wurzel over the succeeding ten years an average of only 14 pounds of nitrogen per acre per annum. Or, reckoned over the whole period of thirty years, after the recent accumulations had been worked out, the root crops gave an average of only 16.4 pounds of nitrogen per acre per annum.

It is remarkable how very similar is the amount of nitrogen annually accumulated in gramineous, cruciferous, and chenopodiaceous crops after the soil had been exhausted of the more recent and more readily available nitrogenous accumulations. Thus, over the second half of the period, the wheat gave 17.2 pounds and the barley 18.8 pounds, against 16.4 pounds over thirty years in the various root crops.

We now come to the yield of nitrogen in leguminous crops. Referring first to the results obtained with beans, it is seen that over the first half of the period of twenty-four years the average annual yield of nitrogen in the crop was 61.5 pounds per acre, while over the second twelve years—in three of which the crop failed, so that there were only nine years of beans, one of wheat, and two of fallow—the annual yield was less than half as much, or only 29.5 pounds per acre. Nevertheless, the average yield over the twenty-four years without any nitrogenous manure was 45.5 pounds per acre per annum. That is to say, under very similar conditions as to soil supply, the highly nitrogenous leguminous crop, beans, has yielded over a given area twice as much nitrogen as either wheat or barley and more than twice as much as the root crops.

The last results in the table relate to the leguminous crop, clover. It is well known that clover fails when it is attempted to grow it too frequently on the same land; and, in the case recorded in the table, it happened that clover was obtained in only six years out of the twenty-two for which the yield of nitrogen is given, so that there are included, owing to the failures, one year of wheat, three of barley, and twelve of fallow. Notwithstanding this there was, with the occasional interpolation of the clover, an average yield over the twenty-two years of 39.8 pounds of nitrogen per acre with mineral, but without nitrogenous supply.

The next illustrations show more strikingly still the greater yield of nitrogen in leguminous than in gramineous crops, when grown under equal soil conditions. They relate to the yield of nitrogen in barley and in clover, grown side by side in the same field, and the results are given in Table 33.

TABLE 33.—*Nitrogen per acre in barley and in clover grown in Little Hoosfield, Rothamsted.*

	Nitrogen per acre.
1873:	*Pounds.*
Barley	37.3
Clover	151.3
1874:	
Barley—	
After barley	39.1
After clover	69.4
Barley after clover more than after barley	30.3

The field had grown one crop of wheat, one of oats, and three of barley in succession, with artificial mineral and nitrogenous manures, but without any farmyard or other organic manure. In 1872 barley was again sown; on one-half alone and on the other half with clover. In 1873 barley was again grown on the one-half, but the clover on the other. The table shows that the barley yielded 37.3 pounds of nitrogen per acre, whilst the three cuttings of clover contained 151.3 pounds. In the next year (1874) barley was grown over both portions, and on the one where barley had yielded 37.3 pounds of nitrogen in the previous year it now yielded 39.1 pounds; but on the portion where the clover had yielded 151.3 pounds the barley succeeding it yielded 69.4 pounds. That is to say, the barley yielded 30.3 pounds more nitrogen after the removal of 151.3 pounds in clover than after the removal of only 37.3 pounds in barley.

The fact is that the clover had not only yielded so much more nitrogen in the removed crops, but it had also left the surface soil considerably richer in nitrogen. Thus, in October, 1873, after the removal of the barley and the clover, samples of soil were taken from ten places on each of the two portions, and the nitrogen was determined in the samples, from each of four of the individual holes separately; in the mixture of the four, and in the mixture of the samples from the other six places. The determinations in the numerous separate samples consistently showed that, to the depth of 9 inches, the clover-land soil, which had yielded so much more nitrogen in the crops, was nevertheless determinably richer in nitrogen than the barley-land soil, which had yielded so much less. This is sufficiently illustrated by the following figures, showing the mean percentage of nitrogen in October, 1873, in the fine dry soil of the clover land and of the barley land, respectively:

	Mean per cent N.
In clover-land soil	0.1566
In barley-land soil	.1416

This was the case, notwithstanding that all visible vegetable débris had first been removed from the samples. It was further found that the above and under ground vegetable residue picked from the clover-land samples was much more in quantity and contained much more

nitrogen than that from the barley-land samples. In 1874 and in 1875 barley only was sown over both portions. In 1876 barley was again sown over the whole of the land, with clover as well on the portions where it had grown in 1873; but the plant failed in the winter and gave no crop in 1877. In 1877 barley was again sown over the whole, this time with clover on half of the previously clover portion and on half of the previously only barley portion. In the autumn of 1877 soil samples were again taken, this time from four places on each of the differently cropped portions. The determinations of nitrogen in the surface soils consistently showed, as before, a higher percentage where clover than where only barley had grown.

It is, of course, well known in agriculture that the growth of clover, which removes much more nitrogen than a cereal crop, increases the produce of a succeeding cereal, as if nitrogenous manure had been applied. But what I wish specially to direct attention to is the fact that a leguminous crop accumulates a great deal more nitrogen over a given area than a gramineous one under equal soil conditions. But not only is the yield of nitrogen per acre much less in the cereal crops, but the percentage of nitrogen in the dry substance of the gramineous produce is much less than in that of the leguminous produce. The corn of the leguminous crops—beans and peas, for example—contains more than twice as high a percentage of nitrogen in its dry substance as that of the gramineous grains. The dry substance of leguminous straws also contains about twice as high a percentage of nitrogen as that of cereal straws. Again, the dry substance of clover hay contains not far short of twice as much nitrogen as that of meadow hay. Lastly, the dry substance of roots contains about the same percentage of nitrogen as that of the cereal grains, but only about half as much as that of the leguminous corn. The leaves of the root crops are, however, high in nitrogen.

The general result is, then, that the nonleguminous crops, especially those of the gramineous family, are characterized both by yielding much less nitrogen in their produce over a given area, and by containing a much lower percentage of nitrogen in their dry substance than the leguminous crops. Bearing these facts in mind, let us now turn to the consideration of the effects of direct nitrogenous manures on the various crops.

EFFECTS OF NITROGENOUS MANURES IN INCREASING THE PRODUCE OF VARIOUS CROPS.

It is fully recognized that, under the conditions in which the crops are grown in ordinary agriculture, nitrogenous manures have very marked effects in increasing the amounts of produce of wheat, of barley, of turnips, of mangels, and of potatoes; that is, of the comparatively low-in-nitrogen nonleguminous crops. It is to be borne in mind, too, that in the case of wheat and barley the increased produce consists, characteristically, of the nonnitrogenous substances starch and cellu-

lose, in that of the root crops of the nonnitrogenous substance sugar, and in that of potatoes of the nonnitrogenous substance starch.

The influence of nitrogenous manures in increasing the production of the nonnitrogenous constituents of our crops is very strikingly illustrated by the results given in Table 34.

TABLE 34.—*Estimates of the yield and gain of carbon, and of the gain of carbohydrates, per acre per annum, in various experimental crops grown at Rothamsted.*

	Carbon.		Carbohydrates.	
	Actual.	Gain.	Gain.	For 1 nitrogen in manure.
Wheat, 20 years, 1852–71:	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Mineral manure	988	....	....	....
Mineral manure and 43 pounds nitrogen as ammonia	1,590	602	1,240	28.8
Mineral manure and 86 pounds nitrogen as ammonia	2,222	1,234	2,550	29.7
Mineral manure and 86 pounds nitrogen as nitrate	2,500	1,512	3,140	36.5
Barley, 20 years, 1852–71:				
Mineral manure	1,138	....	....	....
Mineral manure and 43 pounds nitrogen as ammonia	2,088	950	1,992	46.3
Sugar beet, 3 years, 1871–73:				
Mineral manure	1,123	....	....	....
Mineral manure and 86 pounds nitrogen as ammonia	2,600	1,477	3,188	37.1
Mineral manure and 86 pounds nitrogen as nitrate	3,031	1,908	4,052	47.1
Mangel-wurzel, 8 years, 1876–83:				
Mineral manure	759	....	....	....
Mineral manure and 86 pounds nitrogen as ammonia	1,889	1,130	2,376	27.6
Mineral manure and 86 pounds nitrogen as nitrate	2,129	1,370	2,771	32.2
Potatoes, 10 years, 1876–85:				
Mineral manure	1,021	....	....	....
Mineral manure and 86 pounds nitrogen as ammonia	1,783	762	1,507	17.5
Mineral manure and 86 pounds nitrogen as nitrate	1,752	731	1,416	16.5
Beans, 8 years, 1862 and 1864–70:				
Mineral manure	726	....	....	....
Mineral manure and 86 pounds nitrogen as nitrate	992	266	474	5.5

The first column of figures shows the estimated amounts of carbon per acre per annum in the total produce of wheat and of barley, in the roots of sugar beet and mangel-wurzel, in the tubers of potatoes, and in the total produce of beans, when each is grown by a complex mineral manure without nitrogen, and also with the same mineral manures with nitrogenous manure in addition. The second column shows the estimated gain of carbon; that is, the increased amount of it assimilated under the influence of the nitrogenous manures. The third column gives the estimated increased production of total carbohydrates under the influence of the nitrogenous manures, and the last column the estimated gain of carbohydrates for one of nitrogen in manure. The calculations are based on the average produce, by the different manures, of wheat over twenty years, of barley over twenty years, of sugar beet over three years, of mangel-wurzel over eight years, of potatoes over ten years, and of beans over eight years.

In calculating the amounts of carbon and of carbohydrates in the crop the amounts of mineral and nitrogenous substances are deducted from the dry substance, and the remainder represents the carbohydrates. The amount of carbon in the nitrogenous substance is calculated, and then that in the carbohydrates, on the assumption that in the wheat,

barley, and beans starch and cellulose are the main products; in the sugar beet and mangel-wurzel, cane sugar, pectine, and cellulose, and in the potatoes, starch and cellulose. Such estimates can, obviously, be only approximations to the truth, but accepted as such they are useful, as conveying some definite impression of the influence of nitrogenous manures on carbon assimilation and on carbohydrate formation.

It is thus seen that, independently of the underground growth, the wheat was estimated to assimilate 988 pounds of carbon per acre per annum under the influence of a complex mineral manure alone, and that the amount was increased to 1,590 pounds by the addition of 43 pounds of nitrogen as ammonium salts; to 2,222 pounds by 86 pounds of nitrogen as ammonium salts, and to 2,500 pounds by 86 pounds of nitrogen as sodium nitrate. Accordingly, as shown in the second column, the increased assimilation of carbon was, by 43 pounds of nitrogen as ammonium salts, 602 pounds; by 86 pounds as ammonium salts, 1,234 pounds, and by 86 pounds as sodium nitrate, 1,512 pounds.

Reckoned in the same way, the increased assimilation of carbon in the barley was, for 43 pounds of nitrogen as ammonium salts, 950 pounds per acre; that is, one and one-half times as much as by the same application in the case of wheat.

In the sugar beet roots (the leaves being left on the land) the increased assimilation of carbon was 1,477 pounds per acre by the application of 86 pounds nitrogen as ammonium salts, and 1,908 pounds by 86 pounds of nitrogen as sodium nitrate. There was, therefore, considerably more increased assimilation of carbon and accumulation of it in the roots of the sugar beet than in the grain and straw of wheat by the same applications of nitrogenous manure.

In mangel-wurzel roots (the leaves being returned to the land) the increased assimilation of carbon was 1,130 pounds by 86 pounds of nitrogen as ammonium salts, and 1,370 pounds by 86 pounds as nitrate; that is, less than in the removed crops (grain and straw) of wheat, and considerably less than in the removed crops (the roots) of sugar beet.

In the potatoes, reckoned on the increased production of tubers only (the tops being left on the land), the increased yield of carbon by 86 pounds of nitrogen as ammonium salts was 762 pounds per acre, and by 86 pounds as sodium nitrate 731 pounds; that is, there was considerably less increased production of starch in potatoes than of sugar in either sugar beet or mangel-wurzel by the same applications of nitrogenous manure.

Lastly, in the leguminous crop—beans, with its high yield of nitrogen per acre, and the high percentage of nitrogen in its dry substance, the increased assimilation of carbon under the influence of nitrogenous manure was comparatively quite insignificant. Thus, there was, by the application of 86 pounds of nitrogen as sodium nitrate, an increased assimilation of carbon of only 266 pounds per acre, or little more than one-sixth as much as in wheat and little more than one-eighth as much as in sugar beet by the same application.

Turning to the figures in the third column, it is seen that there was a very greatly increased production of the nonnitrogenous bodies, the carbohydrates, by the use of nitrogenous manures. Thus, by the use of 43 pounds of nitrogen as ammonium salts, there was an estimated increase of 1,240 pounds of carbohydrates in the grain and straw of wheat, and of 1,992 pounds in those of barley. By the application of 86 pounds of nitrogen as ammonium salts, there was an increased formation of 2,550 pounds of carbohydrates in wheat, of 3,188 pounds in sugar beet, of 2,376 pounds in mangel-wurzel, and of only 1,507 pounds in potatoes, and when 86 pounds were applied as sodium nitrate there was an increased production of 3,140 pounds in wheat, of 4,052 pounds in sugar beet, of 2,771 pounds in mangel-wurzel, and of only 1,416 pounds in potatoes, while compared with these amounts there was by the same application an increase of only 474 pounds of carbohydrates in beans.

The last column shows the estimated increased amounts of carbohydrates produced for one of nitrogen in manure in the different cases. Thus, when 43 pounds of nitrogen were applied as ammonium salts 1 pound of nitrogen in manure gave an increased production of 28.8 pounds of carbohydrates in the grain and straw of wheat, and of 46.3 pounds in those of barley; when 86 pounds nitrogen were applied as ammonium salts 1 pound gave an increase of 29.7 pounds carbohydrates in wheat, 37.1 pounds in the roots of sugar beet, 27.6 pounds in those of mangel-wurzel, and 17.5 pounds in potatoes. Again, when 86 pounds were applied as sodium nitrate 1 pound gave an increase of 36.5 pounds carbohydrates in wheat, 47.1 pounds in sugar beet, 32.2 pounds in mangel-wurzel, 16.5 pounds in potatoes, and only 5.5 pounds in the leguminous crop—beans.

It is natural to ask, What is the explanation of the apparently anomalous result that the crops which are characterized by containing comparatively little nitrogen and by yielding large amounts of nonnitrogenous products—starch, sugar, and cellulose—are especially benefited by the application of nitrogenous manures, and that under their influence they yield greatly increased amounts of those nonnitrogenous bodies? It is, perhaps, little more than stating the facts in another way to say, as is the case, that the luxuriance or activity of growth of all these crops is very greatly enhanced by nitrogenous manures, and that since their special products are these nonnitrogenous substances the natural result of the increased luxuriance is to increase the formation of the bodies which are their essential or characteristic products.

A further possible explanation of the curious result has, however, been suggested.[1] Thus, on purely chemical and physiological grounds, and so far as would appear without any special reference to the fact that in the case of our chief starch and sugar-yielding crops the production

[1] See Vines's lectures on the Physiology of Plants, p. 140 et seq.

of those substances is greatly enhanced by the use of nitrogenous manures, it has been suggested that the substance first formed in the chlorophyll corpuscle from carbon dioxide and water is not starch, but a substance possibly allied to formic aldehyde (CH_2O), which goes to construct proteid, by combining with the nitrogen and sulphur absorbed in the form of salts from the soil, or with the nitrogenous residues of previous decompositions of proteid. It is supposed, however, that starch may, nevertheless, be the first visible product of the constructive metabolism, since, unless protoplasm were being formed, no starch could be produced. This view is partly founded on the consideration of the analogy that would then be established between the formation of starch and that of the carbohydrate (cellulose), which is by some experimenters supposed to be derived directly from protoplasm. It is true that such a supposition is, at any rate, not inconsistent with the conditions which we have seen to be favorable for the increased production of starch and sugar in agricultural plants. At the same time, it is admittedly at present little more than hypothesis. It would, indeed, require more evidence than is at present available to establish such a conclusion, while there are considerations which would lead us to hesitate to adopt the view in question without clear experimental proof. Thus, it seems difficult to suppose that the undoubted connection in some striking cases between the amount of nitrogen taken up by the plant and the amount of starch or sugar formed is to be explained by an assumption which implies that a chief office of the nitrogenous bodies of plants is to serve as intermediate only in the transformations necessary for the formation of the nonnitrogenous substances. The view does not, however, assume that nitrogen is eliminated from the plant in the process, and so lost. Then, again, plants such as many of the Leguminosæ, which are characterized by assimilating relatively very large amounts of nitrogen over a given area of land, and by the formation of very large amounts of proteid in proportion to plant surface, produce relatively small amounts of the carbodydrates. Nor is it irrelevant to refer to the fact that, from theoretical considerations, it was for many years assumed, especially in Germany, in opposition to the teachings of our own numerous direct experiments, that in the animal body the nonnitrogenous substance (fat) was mostly, if not always, produced by the degradation of proteid, the nitrogenous by-products being for the most part, if not entirely, eliminated from the body as waste matter. It is, however, now indubitably established, at any rate in the case of the herbivora, which produce the most fat, that that substance is derived largely, if not exclusively, from the nonnitrogenous constituents of the food, the carbohydrates.

In the case of the supposed transformation in plants, the same prodigal expenditure of the nitrogenous bodies in the formation of the nonnitrogenous is, however, as has been said, not involved.

EFFECTS OF NITROGENOUS MANURES ON LEGUMINOUS CROPS.

I have now to illustrate the influence of nitrogenous manures on various leguminous crops, which, as has been pointed out, are characterized by containing a high percentage of nitrogen in their dry substance, and by assimilating a large amount of nitrogen from some source over a given area of land. It will be seen that the results bring to view some very remarkable failures, but also some not less signal and significant successes.

My first illustrations relate to experiments with beans, grown for many years in succession on the same land, without manure; with a purely mineral manure, consisting of superphosphate, and salts of potash, soda, and magnesia; also with the same mineral manure and nitrogenous manure in addition, supplied either as ammonium salts or as sodium nitrate. Table 35 gives a summary of the results obtained under each of the three conditions as to manuring over a period of thirty-two years of continued or interrupted experiments, from 1847 to 1878, inclusive. The upper division gives the average amount of total produce (corn and straw together) per acre per annum over each of the four eight-yearly periods and over the total period of thirty-two years. But, as there were frequent failures of crop, the lower division of the table gives the average produce per acre per annum over the years of crop only during each period.

TABLE 35.—*Beans—Average produce per acre per annum.*

Years.	Total produce (corn and straw).		
	Unmanured.	Mixed mineral manure (including potash).	Mixed mineral manure and nitrogen.
Average per acre per annum over each 8 years and over the 32 years:	*Pounds.*	*Pounds.*	*Pounds.*
8 years, 1847–54	2,421	[1]3,208	3,555
8 years, 1855–62	1,664	2,466	2,629
8 years, 1863–70	606	1,622	2,198
8 years, 1871–78	864	1,506	1,646
32 years, 1847–78	1,389	[2]2,168	2,507
Average per acre per annum over the years of crop only, each period:			
First 8 years, 8 crops	2,421	[3]3,208	3,555
Second 8 years, 7 crops	1,902	2,818	3,005
Third 8 years, 7 crops	692	1,854	2,513
Fourth 8 years, 4 crops	1,729	3,011	3,292
32 years, 1847–78, 26 crops	1,709	[4]2,688	3,086

[1] 7 years, excluding 1849, in which year the produce was accidentally not weighed.
[2] 31 years, excluding 1849. [3] 7 crops, excluding 1849. [4] 25 crops, excluding 1849.

Before referring to the figures it should be explained that in the first five years the nitrogen applied to the third plat was in the form of ammonium salts. The effects were, however, so small and irregular that the application of nitrogenous manure was then suspended for

some years—indeed, for ten years—after which, it having been observed that nitrates were more beneficial to Leguminosæ than ammonium salts, sodium nitrate was applied instead, in amount supplying 86 pounds nitrogen per acre per annum, or nearly twice as much as had been given as ammonium salts in the earlier years. This application of the nitrate commenced in 1862, and, with some breaks owing to severe or wet winters, which prevented the seed being sown or destroyed the plant, it was continued up to 1878, when the experiments were finally abandoned.

The occasional entire failures, above referred to as mainly due to adverse seasons, were also materially dependent on the conditions induced in the land by the continuous cropping with this plant, which, as is the case with most Leguminosæ, is very susceptible to parasitic attacks of various kinds when the conditions of growth are not normal and favorable. Indeed, when there was not absolute failure there was a general tendency to decline in yield, and then to recover again, more or less, after a break. This was somewhat marked after a year of fallow in 1860, and the growth of wheat in 1861, after which there was, in 1862, fair produce, especially on the third plat, where the nitrate was now applied. The land was again fallow in 1863, and this was again followed by improved growth, after which there was declining produce for a number of years, to 1870, inclusive, and again recovery in 1874, after three years of fallow. This general view of the results is of interest as fixing attention on the great tendency to failure of this leguminous crop, when grown year after year on the same land.

Independently of the occasional entire failures there were also considerable fluctuations from year to year, according to season; and the table shows that there was besides, upon the whole, considerable decline from period to period. Turning now to the effects of the different manures, it is seen that there was, over each period, a considerable increase of produce by the use of the mineral manure containing potash, but that there was comparatively little further increase by the addition of nitrogenous to the mineral manure. Thus, as shown in the upper division of the table, the average annual total produce, over the thirty-two years (which, however, included seven without any bean crop) was—without manure, 1,389 pounds; with the mineral manure alone, 2,168 pounds, and with the mineral and nitrogenous manure together, 2,507 pounds; that is, while the mineral manure without nitrogen gave an average annual increase of 779 pounds, the addition to it of nitrogenous manure only further raised the produce by 339 pounds. Or if, instead of taking the average of the thirty-two years, we take it only over the twenty-six years in which there was any bean crop, as shown in the lower division, the average total produce was—without manure, 1,709 pounds; with purely mineral manure, 2,688 pounds, and with the mineral and nitrogenous manure together, 3,086; that is, there was an annual average increase of 979 pounds by the

mineral manure containing potash, and of only 398 pounds more by the addition of nitrogenous manure.

It may be added that details not given in the table further show that in two of the last eight years the total produce was, without manure, only exceeded three or four times during the whole period, namely, during the first five years; with mineral manure alone it was only exceeded four or five times, and with the mineral and nitrogenous manure together it was only exceeded six times. Indeed, the table shows that on both of the manured plats the average total produce over the last four years of actual crop (with four of fallow in the eight years) was nearly as much as the average of the first eight years of crop. Thus, with the purely mineral manure, the average total produce of the first eight years was 3,208 pounds, and over the last four years of crop it was 3,011 pounds, and with the mineral and nitrogenous manure it was, over the first eight years, 3,555 pounds, and over the last four years of crop, 3,292 pounds. It will be seen further on that the average annual yield of nitrogen was also nearly as great over the last four years of crop as over the first eight years.

It may be observed that nitrogen supplied as ammonium salts to the highly nitrogenous leguminous crop seldom gives any increase, and is sometimes injurious in the year of application, though some benefit may afterwards result from the residue after the ammonia has been converted into nitric acid. Even nitrates, however, directly applied as manure, are very uncertain in their action, and at any rate yield very much less increase of produce with the highly nitrogenous Leguminosæ than with the Gramineæ and crops of other orders yielding produce of low percentage of nitrogen in their dry substance and accumulating comparatively little nitrogen over a given area of land.

It is specially to be noted that while the cereal crops may be successfully grown for many years in succession on the same land, provided only that mineral and nitrogenous manures are liberally supplied, this leguminous crop, beans, gradually fails when so grown; and although characteristically benefited by mineral manures containing potash, neither these alone, nor a mixture of mineral and nitrogenous manure, has sufficed to maintain even fair growth for a number of years in succession. The result is, however, not entirely due to deficiency in the supply of constituents within the soil, but is also in a considerable degree dependent on the fact that by the continuous growth of the crop, with its special habit and range of roots, the surface soil acquires a close and unfavorable condition, and a somewhat impervious pan is formed below. The improved result in the later years with the intervention of fallow further illustrates the fact that the previous failures were not wholly due to exhaustion.

The next table (36) shows the amounts of nitrogen in the bean crops, the produce of which we have been considering. The table is on the same plan as that relating to the produce, the upper division giving

the averages for the four eight-yearly periods and for the total period of thirty-two years, and the lower division those for the years of crop only within each period; and, as in Table 35, the results for the total produce only (corn and straw together) are given.

TABLE 36.—*Beans—Yield of nitrogen (average per acre per annum, eight-year periods).*

Periods.	Total produce (corn and straw). Unmanured.	Mixed mineral manure (including potash).	Mixed mineral manure and nitrogen.
Average per acre per annum over each 8 years and over 32 years:	*Pounds.*	*Pounds.*	*Pounds.*
8 years, 1847–54	48.4	[1]60.2	69
8 years, 1855–62	25.3	34.3	36.8
8 years, 1863–70	9.2	23.5	35.1
8 years, 1871–78	16.4	26.7	28.7
32 years, 1847–78	24.8	[2]35.4	42.4
Average per acre per annum over the years of crop only, each period:			
First 8 years, 8 crops	48.4	[3]60.2	69
Second 8 years, 7 crops	28.9	39.2	42.1
Third 8 years, 7 crops	10.4	26.8	40
Fourth 8 years, 4 crops	32.7	53.3	57.4
32 years, 1847–78, 26 crops	30.5	[4]43.9	52.2

[1] 7 years, excluding 1849, in which year the produce was accidentally not weighed.
[2] 31 years, excluding 1849. [3] 7 crops, excluding 1849. [4] 25 crops, excluding 1849.

Referring to the figures in the upper division of the table, it may be observed that notwithstanding there were six blank years and one year of wheat out of the thirty-two, and notwithstanding that the produce declined much and gave on the whole much less than the average obtained under ordinary agricultural conditions, yet the average yield of nitrogen in the crops grown without any supply of it was much more than in either of the cereals, the root crops, or potatoes grown under similar conditions. Thus, as the bottom line of the upper division shows, there was an average over the thirty-two years of 24.8 pounds of nitrogen per acre per annum in the crops without any manure, but of 35.4 pounds with the mineral manure without nitrogen; while the amount was raised to only 42.4 pounds by the addition of nitrogenous manure. Over the first eight years, however, the yield was very much higher, being for the three plats, respectively, 48.4, 60.2, and 69 pounds. Over the second period of eight years the average was not far from that of the whole thirty-two years, but over the third and fourth periods it was much less.

As in the case of the total produce itself, so also in that of the nitrogen in the total produce, if we take the averages of the years of crop only, as given in the bottom division of the table, we have a much higher average yield per annum over the four years of crop of the last eight years than over the years of crop of either the second or third period of eight years. Indeed, on the two manured plats there is an average annual yield of nitrogen per acre over the four years of crop during the last

eight years not very far short of the average of the first eight years. Thus, with the purely mineral manure, there is an average annual yield of nitrogen over the first eight years of 60.2 pounds, and over the four years of crop of the last eight of 53.3 pounds; and, with the mineral and nitrogenous manure together over the first eight years of 69 pounds, and over the four years of crop of the last eight years of 57.4 pounds. That is, with the intervention of fallow, we have, though not good agricultural crops, yet really large yields of nitrogen compared with those obtained in many of the preceding years; and very large yields without any supply by manure, compared with those obtained under the same conditions with any of the nonleguminous crops. It would appear probable, therefore, that if a suitable mechanical condition of the land could have been maintained fair crops and large yields of nitrogen would also have been maintained.

Upon the whole, then, although the crop practically failed when it was thus attempted to grow it year after year on the same land, it nevertheless accumulated in its above-ground produce much more nitrogen over a given area than the crops of the other orders, but was little benefited by an artificial supply of nitrogen.

I have now to record a still greater failure than that with beans, namely, when it was attempted to grow another leguminous crop year after year on ordinary arable land—this time *Trifolium pratense*, or red clover. The results are summarized in Table 37 (p. 102).

The table is headed "red clover sown frequently on the same land." The period of experiment was, in fact, twenty-nine years—from 1849 to 1877, inclusive. But the details, not given in the table, show that although clover was sown fifteen times in the twenty-nine years, in only seven was any clover crop obtained, while about one-fifth of the produce of the whole series of years was yielded in the first year, 1849. It is, indeed, fully recognized that in our own country clover will not grow under ordinary conditions more frequently than once in a certain number of years, which varies according to soil and other circumstances, but is seldom so few as four, and frequently as many as, or more than, eight years. It should be stated that when the clover failed, sometimes a cereal crop, wheat or barley, was sown, but more frequently the land was left fallow. Further, the amounts of produce entered in the column headed series 1 are, in each case, the means of those on three plats, each of which occasionally received a mineral manure containing potash; and the results given in the column series 2 are also the means of three plats, each with the same mineral manure as series 1, and nitrogenous manures occasionally applied in addition.

TABLE 37.—*Red clover sown frequently on the same land (total produce per acre per annum as hay).*

SUMMARY.

Years.	Series 1 (mineral manure alone).	Series 2 (mineral and nitrogenous manures).
Produce:		
29 years, 1849–77—	*Pounds.*	*Pounds.*
Total	52,991	60,689
Average	1,827	2,093
Years of crop only, average	4,416	4,668
Years of clover only (7)—		
Total	29,195	31,886
Average	4,171	4,555
Nitrogen (estimated):		
29 years, 1849–77—		
Total	929.4	1,043.1
Average	32	36
Years of crop only, average	77.5	80.2
Years of clover only (7)—		
Total	700.7	765.3
Average	100.1	109.3

It should be explained that very large crops of clover were obtained in the first year, 1849: less than one-quarter as much in the third year, 1851, and in the fourth about half as much as in the first. No more clover was then obtained until the seventh year, when there was very little. After this there was more or less in the eleventh, seventeenth, twenty-third (on series 2), and lastly (on series 1) in the twenty-seventh year; but in no case, excepting in the fourth year, was the amount of produce half as much as in the first. Comparing the results without and with the nitrogenous manure, the table shows that the average annual total produce of clover hay and other crops was reckoned, over the twenty-nine years, 1,827 pounds without and 2,093 pounds with the nitrogenous manure; and, reckoned in the same way, the average annual yield of nitrogen was, without nitrogenous manure, 32 pounds, and with it 36 pounds. Reckoned, however, over the years of crop only, the yield of nitrogen in the clover and other crops was 77.5 pounds per acre per annum without and 80.2 pounds with the nitrogenous manuring. Or, reckoning the nitrogen in the clover alone, and only over the years when it gave any crops, the average annual yield of it over those seven years was, without nitrogenous manure, 100.1 pounds, and with it, 109.3 pounds. There was, therefore, comparatively little increase, either in the produce or in the yield of nitrogen by the use of nitrogenous manures.

To conclude in regard to these experiments: The attempt to grow clover year after year on this ordinary arable land by means of such mineral manures as increase the luxuriance of growth when there is a fair plant, or even by the addition to these of nitrogenous manures, has entirely failed. In view of this failure to grow the crop continuously on ordinary arable land the next results to which I have to call attention are of much interest and significance.

GROWTH OF RED CLOVER YEAR AFTER YEAR ON RICH GARDEN SOIL.

In 1854, after it seemed clear that the plant would not continue to grow on the arable land, clover was sown in a garden, only a few hundred yards distant from the experimental field, on soil which had been under ordinary kitchen garden cultivation for probably two or three centuries. It is remarkable that, under these conditions, the crop has grown luxuriantly almost every year since, this year (1893) being the fortieth season of the continuous growth. Further particulars will be given on the point presently, but it may here be premised that, at the commencement, the percentage of nitrogen in the surface soil of the garden was four or five times as high as in that of the arable soil in the field; and it would doubtless be richer in all other manurial constituents also. Indeed, after the growth of clover for twenty-five years in succession, even the second 9 inches of depth was found to be still very much richer in nitrogen than the first 9 inches in the field.

Table 38 (p. 104) gives the results for each of the forty years of experiment with clover on the rich garden soil. The first column after the dates shows the number of cuttings each year, the second the amounts of produce per acre, reckoned in the condition of dryness as hay, the third the amount of dry substance, the fourth that of the mineral matter, and the last the estimated amounts of nitrogen per acre in the crops. At the bottom of the table are given the average annual results over periods of ten, ten, ten, ten, and forty years.

It should be stated that, as the garden clover plat is only a few yards square, calculations of produce per acre can only give approximations to the truth, but it is believed that they can be thoroughly relied upon so far as their general indications are concerned. It may be added that five times during the whole period gypsum has been applied to one-third, and a mineral manure containing potash but no nitrogen to

TABLE 38.—*Red clover grown year after year on rich garden soil, forty years, 1854–1893—Hay, dry matter, mineral matter, and nitrogen (per acre per annum).*

Years.	Number of cuttings.	As hay.	Dry matter.	Mineral matter.	Nitrogen (estimated).	Seed sown.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	
1854	2	5.191	4,326	435	125	1854, March.
1855	3	18.113	15,094	1,560	435	
1856	2	11,027	9,190	1,116	265	
1857	3	14,855	12,379	1,384	357	
1858	2	7.608	6,340	792	183	
1859	2	6.227	5,189	687	149	
1860	1	8.679	7,233	806	208	1860, May.
1861	2	13.353	11.128	1.285	321	
1862	2	10,042	8,368	991	241	
1863	2	11,798	9,832	971	283	
1864	2	5.506	4,583	446	132	
1865	1	2,044	1,704	190	49	1865, April.
1866	2	10.456	8,713	908	251	
1867	2	6,748	5,624	573	162	
1868	1	991	826	106	24	1868, April.
1869	2	4,183	3,486	387	100	
1870	1	1,741	1,451	148	42	
1871	1	4,513	3,761	458	108	1871, April.
1872	2	10,142	8,452	899	243	
1873	2	9.287	7,740	772	223	
1874	3	5,899	4.916	540	142	1874, May and July.
1875	1	2,731	2,276	230	66	1875, July and September.
1876	2	3,517	2.931	279	84	1876, September.
1877	1	3,533	2.944	326	85	1877, May.
1878	3	13,416	11.180	1,336	322	
1879	1	2,738	2,282	428	66	1879, May.
1880	2	5,742	4,785	643	138	1880, April.
1881	2	4,262	3,552	330	102	1881, April (mended).
1882	3	6,433	5,361	641	154	1882, April (mended).
1883	1	2,716	2,264	315	65	1883, May.
1884	3	9,990	8,325	863	240	
1885	3	6,511	5,426	615	156	
1886	1	2,702	2,252	313	65	1886, April.
1887	2	3,287	2,739	264	79	1887, April (mended).
1888	1	1,841	1,535	211	44	1888, April (mended June).
1889	2	8,664	7,221	754	208	1889, April (mended).
1890	1	2,817	2,348	367	68	1890, April.
1891	2	6.696	5,580	574	161	1891, May (mended).
1892	1	3,568	2,973	355	86	1892. May 7 (May 27, mended).
1893	2	5.941	4,951	500	143	1893, April (mended).
Average per acre per annum.						
10 years, 1854–63	....	10,689	8.908	1,003	257	
10 years, 1864–73	....	5,561	4.634	489	133	
10 years, 1874–83	....	5,099	4.249	507	122	
10 years, 1884–93	....	5,202	4 335	482	125	
40 years, 1854–93	....	6,638	5,532	620	159	

I shall confine attention to the amounts of produce reckoned as hay, and to the estimated amounts of nitrogen in the produce. Casting the eye down the column of produce as hay, it is seen at a glance that, excepting a few occasional years of very high produce during the later periods, the amount of crop is very much greater during the first than during either of the subsequent periods of ten years each. In fact, as is seen at the foot of the table, there was an average annual produce equal to 10,689 pounds of hay over the first period of ten years, but of only 5,561 pounds over the second, 5,099 pounds over the third, and 5,202 pounds over the last ten years. Now, even these latter amounts correspond to what would be considered fair, though not large crops, when clover is grown in an ordinary course of rotation once only in

four or in eight years or more; so that the produce in the earlier years on this rich garden soil was very unusually heavy. Indeed, the average annual produce over the whole period of forty years, namely, 6,638 pounds, or nearly 3 tons of hay, would be a very good yield for the crop grown only occasionally in the ordinary course of agriculture. But it is when we look at the figures in the last column of the table, which show the estimated amounts of nitrogen in the crops, that the importance and significance of these results obtained on rich garden soil are fully recognized; and this is especially the case when they are compared with those obtained on ordinary arable land. Thus, the amount of nitrogen in fair crops of wheat, barley, or oats, will be from 40 to 50 pounds per acre; of beans, about 100 pounds; of meadow hay, about 50 pounds, and of clover grown occasionally in rotation, from 100 to 150 pounds. But here, on this rich garden soil, the produce of clover has in one year contained more than 400 pounds of nitrogen, in three years more than 300 pounds, in several more than 200 pounds, and in only thirteen years of the forty less than 100 pounds. In fact, as the figures at the bottom of the table show, the estimated average annual yield of nitrogen in the above-ground growth was: Over the first ten years, 257 pounds; over the second ten years, 133 pounds; over the third ten years, 122 pounds; over the last ten years, 125 pounds; and over the whole period of forty years, 159 pounds; while, as the details show, the yield of nitrogen in the thirty-first year (1884) was about 240 pounds, in the thirty-second year 156 pounds, in the thirty-sixth year 208 pounds, in the thirty-eighth year 138 pounds, and in the fortieth year 143 pounds. Further, the averages over the second, third, and fourth ten years of the continuous growth (133, 122, and 125 pounds) were about as much as in a fair but not large crop grown occasionally under the ordinary conditions of agriculture; while the average of the forty years, 159 pounds, is as much as in a really good crop grown occasionally in rotation. There would seem, then, to be clearly indicated a soil source of failure on the arable land and a soil source of success on the garden soil.

The results given in Table 39 will throw some further light on this point. It shows the percentage of nitrogen in the first 9 inches of depth of the garden soil in 1857 and in 1879, between which periods the growth of twenty-one years had been removed. It also shows the estimated amounts of nitrogen per acre in the surface soil at the two periods and the reduction in the amount during the twenty-one years.

TABLE 39.—*Red clover grown on rich garden soil—Nitrogen (per cent and per acre) in the fine soil dried at 100° C., first 9 inches of depth.*

	1857 (per cent, 0.5095).	1879 (per cent, 0.3634).	Difference (per cent, 0.1461).
	Pounds.	*Pounds.*	*Pounds.*
Per acre (total)	9,528	6,796	2,732
Per acre per annum (21 years)	....	....	130

It may be mentioned that the percentage of nitrogen given for the sample collected in October, 1857, is the mean of duplicate or more determinations made in 1857, in 1866, and again in 1880, and it is almost identical with the results obtained at the latest of these dates. The first point to notice is that the first 9 inches of depth of this rich garden soil contained more than half a per cent of nitrogen; that is, nearly four times as much as the average of the Rothamsted arable soils and nearly five times as much as the exhausted arable clover-land soil, where the crop failed. It is, of course, true that the garden soil would be correspondingly rich in all other constituents; but some portions of the arable soil where the clover failed had received much more of mineral constituents by manure than had been removed in the crops.

The result given for 1879 is the mean of determinations made on three separate samples, for which the determinations agreed very well. The results can leave no doubt that there had been a great reduction in the stock of nitrogen in the surface soil since 1857. The reduction amounts to nearly 29 per cent of the whole in the twenty-one years, and, reckoned per acre, it corresponded, as shown in the table, to a loss of 2,732 pounds during the twenty-one years; and although, as has been seen, fairly average, and even good crops were still grown, it is obvious that coincidently with this great reduction in the stock of nitrogen in the surface soil there has been a very marked reduction in the clover-growing capability of the soil. On this point it may be mentioned that, while fresh seed was only sown five times during the first twenty of the forty years, it has been fully or partially sown twenty-one times during the last twenty years. It is obvious, therefore, that the plant was able to stand very much longer in the earlier than in the later condition of the soil. Indeed, both the reduced pert sistence of the plant and the reduced produce have been coinciden- with a considerable reduction in the stock of nitrogen in the soil.

The question arises, What relation does the amount of nitrogen lost by the soil bear to the amount taken off in the crops? It is admittedly necessary to accept with some reservation results of calculations of produce per acre from amounts obtained on a few square yards, but the general indications may doubtless be trusted. Such estimates show more than 160 pounds of nitrogen to have been removed per acre per annum in the crops over the twenty-one years, while the estimated loss of the surface soil corresponds to about 130 pounds per acre per annum; that is to say, the loss by the surface soil is sufficient to account for a large proportion of the nitrogen removed in the crops. There is, however, evidence leading to the conclusion that when excessive amounts of farmyard manure have been applied, as had been the case with this garden soil, there may be some loss by the evolution of free nitrogen, and obviously, so far as this may have occurred, there will be the less of the ascertained loss to be credited to assimilation by the growing clover. On the other hand, it is known that when growing

on ordinary arable soil the clover plant throws out a large amount of feeding root in the lower layers, and although. in the case of so rich a surface soil, the plant may derive a larger proportion of its nutriment from that source, we must at the same time suppose that it has also availed itself of the resources of the subsoil. Unfortunately, in 1857 samples were only taken to a depth of 9 inches, so that no comparison can be made of the condition of the subsoil at the two periods. In 1879, however, the second 9 inches of the garden soil was found to contain a much higher percentage of nitrogen than the first 9 inches of the clover-exhausted arable field, and about three times as high a percentage as the subsoil of the arable field at the same depth. It can not be doubted, therefore, that the subsoil of the garden plat has contributed nitrogen to the clover crops. Here, then, notwithstanding the very little effect of direct nitrogenous manures on either the beans or the clover growing on the ordinary arable land, there would seem to be very clear evidence of a soil source of, at any rate, much of the enormous amounts of nitrogen assimilated over a given area by the clover growing on the rich garden soil.

It may here be observed that in experiments on the mixed herbage of permanent grass land in which the growth of leguminous herbage was much increased by the application of mineral manure containing potash it was found at the end of twenty years that the amount of nitrogen in the surface soil had been considerably reduced, compared with that of a plat which had been unmanured, and had yielded very much less leguminous herbage. The conclusion was that. as in the case of the clover growing on the rich garden soil, the nitrogen of the surface soil had been a source of, at any rate, much of the nitrogen of the increased produce of Leguminosæ in the mixed herbage of the grass land.

RED CLOVER GROWN AFTER BEANS.

After the cessation of the experiment with beans in 1878 the land was left fallow for between four and five years, to 1882, inclusive, when grass seeds were sown, but failed. On this land, on which the attempt to grow the leguminous crop, beans, year after year had failed and been abandoned, barley and clover were sown in the spring of 1883. In April, 1883, however, before the barley and clover were sown, the surface soil (free of stones and reckoned dry) of the plat which had been entirely unmanured during the thirty-two years of the experiments with the beans was found to contain 0.0993 per cent of nitrogen, that of the mineral-manured plat 0.1087 per cent, and that of the plat which had received both the mineral and nitrogenous manures 0.1163 per cent, amounts which show considerable nitrogen exhaustion of the surface soil.

Also in 1883, the nitrogen as nitric acid was determined in samples, each of 9 inches of depth, down to a total depth of 72 inches. In the case of several plats the results show, calculated per acre, that the

total amount of nitrogen as nitric acid to the depth of eight times 9 inches, or 72 inches in all, was 27.95 pounds in the unmanured plat, 20.72 in that with purely mineral manure, and 25.38 pounds in that of the plat which had received both mineral and nitrogenous manure. In the soil of the farmyard manure plat, on the other hand, the amount was about twice as much, namely, 50.46 pounds. Excluding this last result, it may be said that the amounts of nitrogen already existing as nitric acid, to the depth determined, were very small. These, then, were the conditions of the soil when the barley and clover were sown in the spring of 1883. The clover grew very luxuriantly from the first, so much so as to considerably interfere with the growth of the barley.

Table 40 shows the amounts of nitrogen per acre in the barley and clover in 1883, and in the clover in 1884 and 1885.

TABLE 40.—*Barley and clover grown after beans, Geescroft field—Nitrogen removed per acre in the crops.*

Previous condition of manuring.	Barley and clover, 1883.	Clover, 1884.	Clover, 1885.	Total.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
Without manure	45	183.2	52.7	280.9
Mineral manure and some nitrogen	57.2	193.1	79.9	330.2
Mineral manure only	59.3	206.4	81.6	347.3

It should be stated that the plats, the yield of nitrogen of which is here given, do not exactly correspond with those for which the yield of nitrogen in the beans was given; some of the barley and clover crops having been taken together where no difference in the produce was observable. Thus, half the plat represented as without manure had been unmanured from the commencement, that is, for nearly forty years, but the other half received some nitrogen to 1878, inclusive, but had since been entirely unmanured. Again, the results given in the second line relate to the produce of a plat part of which received purely mineral manure, but the other part ammonium salts or nitrate up to 1878, but none since. The results given in the third line relate, however, to a plat which has not received any nitrogenous manure from the commencement of the experiments with the beans, but which was not brought under experiment until five years later than the other plats. Thus, on a plat where a purely mineral manure, containing potash, but no nitrogen, had been applied for twenty-seven years, to 1878, inclusive, and no manure since, 347.3 pounds of nitrogen were gathered per acre, almost wholly by the leguminous crop, clover. On a plat on part of which the mineral manure only, and on part the same mineral manure and ammonium salts or nitrate, had been applied up to 1878, but nothing since, 330.2 pounds of nitrogen were removed in the crops. Lastly, where to half of the plat no manure whatever had been applied for nearly forty years, but to the other half ammonium salts or nitrate up to 1878, the yield of nitrogen in the barley and clover was 280.9 pounds.

Here, then, in a field where beans had been grown for many years in succession, and had yielded much less than average crops, and the land had then been left fallow for several years; where the surface soil had become very poor in total nitrogen; where both surface soil and subsoil were very poor in ready-formed nitric acid, and where there was a minimum amount of crop residue near the surface for decomposition and nitrification, there were grown very large crops of clover, containing very large amounts of nitrogen. Not only was so much nitrogen removed in the crops, but the surface soils became determinably richer in nitrogen as the results in Table 41 show. There are there given the percentages of nitrogen in the sifted dry surface soil of the three plats for which the produce and the nitrogen in the beans have been given. The results relate to samples taken in April, 1883, before the sowing of the barley and clover, and in November 1885, after the removal of the crops. The first two columns show the percentages of nitrogen, and the other columns the calculated amounts of it per acre in the surface soils, 9 inches deep, at the different dates; also the estimated gain of nitrogen under the influence of the growth of the clover.

TABLE 41.—*Nitrogen in surface soils before and after growth of barley and clover.*

	Per cent.		Per acre.		
	1883.	1885.	1883.	1885.	1885 + or —1883.
	Per cent.	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*
1. Without manure	0.0993	0.1083	2,441	2,662	+ 221
2. With mineral manure containing potash	.1087	.1149	2,672	2,824	+ 152
3. With mineral manure and nitrogen	.1163	.1225	2,859	3,011	+ 152

Without assuming that the figures represent accurately the amounts of nitrogen accumulated per acre, it can not be doubted that the surface soils had become considerably richer. If, for the sake of illustration, we assume that 300 pounds of nitrogen were removed per acre in the crop, and that 150 pounds were accumulated in the surface soil, we have 450 pounds of nitrogen to account for, as gathered by the crops within a period of little more than two years.

It is clear that we have in the experimental results themselves no conclusive evidence as to the source of so large an amount of nitrogen. As the surface soil became determinably richer, it is obvious that it must have been derived either from above or below it, from the atmosphere or from the subsoil; and if from the subsoil, the question arises whether it was taken up as nitric acid, as ammonia, or as organic nitrogen. But it must be admitted that there is nothing in the experimental results themselves to show that so large an amount of nitrogen could have been available as nitric acid. There remains the question whether the free nitrogen of the atmosphere has in any way been brought into combination either within the soil or within the plant. Evidence on these points will be adduced further on.

VARIOUS LEGUMINOUS PLANTS GROWN AFTER RED CLOVER.

I have now to adduce another and even much more striking instance of successful growth and of great accumulation of nitrogen by plants of the leguminous order on soil where another plant of the same order had failed, and where the surface soil had become very poor in nitrogen.

The experiments were made on the plats where it had been attempted to grow red clover year after year on ordinary arable land; where, in fact, clover had been sown twelve times in thirty years, and where, in eight out of the last ten trials, the plant had died off in the winter and spring succeeding the sowing of the seed, in four cases without any crop at all, and in the other four yielding very small cuttings.

In 1878 the land was devoted to experiments with various leguminous plants, differently manured, having regard, however, to the previous manurial history of the plats. The object was to ascertain whether, among a selection of plants all belonging to the leguminous order, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time and would yield more produce containing more nitrogen, as well as other constitutents, than others, all being supplied with the same descriptions and quantities of manuring substances applied to the surface soil. Further, whether the success in some cases and the failure in others would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of red clover when grown too frequently on the same land.

Accordingly, 14 different Leguminosæ were selected and sown in 1878. These included 8 species or varieties of Trifolium, 2 species of Medicago, *Melilotus leucantha*, *Lotus corniculatus*, *Vicia sativa*, and *Lathyrus pratensis*. Of these, 6 of the 8 Trifoliums have already failed and been replaced by other plants, as also have the *Medicago lupilina*, the *Lotus corniculatus*, and the *Lathyrus pratensis*, the last being replaced in the second year by *Onobrychis sativa*. The plants which have maintained fair but very varying character of growth are the *Trifolium repens*, *Vicia sativa*, *Melilotus leucantha*, and *Medicago sativa;* and I propose to give some account of the growth of these plants on the clover-exhausted soil.

That the surface soil had become very poor in nitrogen is evident from the fact that the mean percentage of it in the sifted dry surface soil of five of the clover plats was, in March, 1881, only 0.1058, which is considerably lower than was found in the same field many years before, and lower than has been found in any of the fields at Rothamsted, excepting those where crops have been grown for many years on the same land without nitrogenous manure. It is a point of interest, however, that the percentage in the surface soil was not so low as in immediately adjoining land which had been under alternate wheat and fallow for nearly thirty years without manure.

The real interest of the results depends on the amounts and on the difference in the amounts of nitrogen which the various plants have assimilated over a given area, all growing side by side on the same red clover-exhausted land and with the same mineral manures without any supply of nitrogen.

Accordingly, the upper part of Table 42 shows the estimated average amounts of nitrogen in the gramineous crop, wheat, grown in alternation with fallow, over twenty-seven years to 1877, inclusive, and in the red clover (together with other crops when it failed), over twenty-nine years, also to 1877, inclusive. Then in the body of the table are given the amounts of nitrogen in the wheat alternated with fallow and in the produce of five different leguminous plants during the subsequent years, commencing with 1878, and extending in some cases to 1891.

TABLE 42.—*Estimated yield of nitrogen per acre (in pounds) in wheat alternated with fallow and in various leguminous crops without nitrogenous manure.*

[Preliminary period, wheat and fallow, 27 years, 1851–77; red clover, etc., 29 years, 1849–77.]

	Unmanured.	Mineral manures only.				
	Fallow wheat.	Trifolium pratense.	Trifolium repens.	Vicia sativa.	Melilotus leucantha.	Medicago sativa.
Average per acre per annum ...	15	32				
[Experimental period.]						
1878	14	0	0	51	53	0
1879	5	50	82	46	130	0
1880	12	8	0	58	36	28
1881	9	21	8	65	60	28
1882	9	18	74	146	145	111
1883	13	0	0	101	27	143
1884	15	0	0	113	56	337
1885	16	15	97	90	58	270
1886	7	Lupines.	16	52	0	167
1887	13	0	6	64	82	247
1888	9	Medicago sativa.	0	60	32	161
1889	9		0	65	23	153
1890	14		Fallow.	61	Trifolium pratense.	124
1891	18		Faba vulg.	79		147
Total, 14 years, 1878–91	163	[1]112	[2]283	1,051	[2]702	1,916
Average, 14 years, 1878–91	12	[1]14	[2]24	75	[2]58	137
Average for years of crop	12	22	47	75	64	160

[1] Eight years only, 1878–1885. [2] Twelve years only, 1878–1889.

Thus, over the preliminary period, the wheat gave an average annual yield of nitrogen per acre of 15 pounds, and the clover gave, over much the same period, an average of 32 pounds of nitrogen. Against these amounts the various crops yielded over the subsequent years averages per acre per annum as follows: The fallow wheat, over fourteen years, 12 pounds; the red clover (*Trifolium pratense*), over eight years, 14 pounds; the white clover (*Trifolium repens*), over twelve years, 24 pounds; the vetch (*Vicia sativa*), over fourteen years, 75 pounds; the Bokhara clover (*Melilotus leucantha*), over twelve years,

58 pounds, and the lucern (*Medicago sativa*), over twelve years, 137 pounds. Or, if we take the average amounts over the years of actual crop only, they were: In the wheat, 12 pounds; in the red clover, 22 pounds; in the white clover, 47 pounds; in the vetch, 75 pounds; in the Bokhara clover, 64 pounds; and in the lucern the enormous amount of 160 pounds of nitrogen per acre per annum.

Again, if we take the total yields of nitrogen over the experimental periods, we have: In the wheat, 163 pounds; in the red clover, 112 pounds; in the white clover, 283 pounds; in the vetch, 1,051 pounds; in the Bokhara clover, 702 pounds; and in the lucern, 1,916 pounds. That is, in the lucern about twelve times as much as in the wheat, nearly twice as much as in the vetch, and very much more than in either of the other Leguminosæ. Indeed, this very deeply and very powerfully rooting plant yielded, in its above-ground produce alone, 337 pounds of nitrogen in 1884, 270 pounds in 1885, 167 pounds in 1886, 247 pounds in 1887, and an average of 146 pounds over the next four years.

Not only have these large amounts of nitrogen been removed in the above-ground produce, but determinations of nitrogen in the soils of the vetch plat in 1883, and of the white clover, the Bokhara clover, and the lucern plats in 1885, have shown, as in the case of the clover after the beans, that the surface soil had gained rather than lost nitrogen, due to the accumulation of nitrogenous crop residue. Here again, then, it is obvious that the original source of the nitrogen of the crops has not been the surface soil itself. It must have been derived either from the atmosphere or from the subsoil.

The next results will throw some light on this point. Thus, having made initiative experiments of the same kind some years previously, in July, 1883, samples of soil were taken to the depth of 12 times 9 inches, or 108 inches in all, on the wheat fallow plat, on the white clover plat, and on two of the vetch plats for the determination of the amount of nitrogen existing as nitric acid at each depth. Table 43 summarizes the results.

TABLE 43.—*Nitrogen as nitric acid (per acre, pounds) in soils of some experimental plats without nitrogenous manure for more than thirty years, Hoosfield, Rothamsted.*

[Samples collected July 17 to 26, 1883.]

Depths.	Wheat, fallow land (unmanured).	Trifolium repens (series 1, plat 4).	Vicia sativa, (series 1, plat 4).	Vicia sativa (series 1, plat 6).	Trifolium repens + or — wheat land.	+ or — Trifolium repens.	
						Vicia sativa (plat 4).	Vicia sativa (plat 6).
Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1–9	19.85	30.90	12.16	10.22	+11.05	—18.74	—20.68
10–18	8.05	27.73	4.11	2.72	+19.68	—23.62	—25.01
19–27	2.47	8.44	1.37	1.08	+ 5.97	— 7.07	— 7.36
28–36	2.70	7.64	1.67	1.52	+ 4.94	— 5.97	— 6.12
37–45	1.62	9.07	4.58	2.51	+ 7.45	— 4.49	— 6.56
46–54	3.57	8.77	6.37	4.42	+ 5.20	— 2.40	— 4.35
55–63	3.84	7.92	7.16	4.52	+ 4.08	— 0.76	— 3.40
64–72	2.28	8.34	5.95	4.92	+ 6.06	— 2.39	— 3.42
73–81	1.48	8.27	4.54	4.81	+ 6.79	— 3.73	— 3.46
82–90	1.76	9.95	5.32	5.14	+ 8.19	— 4.63	— 4.81
91–99	2.94	9.16	5.66	6.40	+ 6.22	— 3.50	— 2.76
100–108	1.84	9.51	5.32	6.46	+ 7.67	— 4.19	— 3.05
SUMMARY.							
1–27	30.37	67.07	17.64	14.02	+36.70	—49.43	—53.05
28–54	7.89	25.48	12.62	8.45	+17.59	—12.86	—17.03
55–81	7.60	24.53	17.65	14.25	+16.93	— 6.88	—10.28
82–108	6.54	28.62	16.30	18	+22.08	—12.32	—10.62
1–54	38.26	92.55	30.26	22.47	+54.29	—62.29	—70.08
55–108	14.14	53.15	33.95	32.25	+39.01	—19.20	—20.90
1–108	52.40	145.70	64.21	54.72	+93.30	—81.49	—90.98

The first point to notice is that at each depth, from the first to the twelfth, the *Trifolium repens* soil contained much more nitrogen as nitric acid than the wheat fallow soil; and, as the figures at the bottom of the table show, while to the total depth of 108 inches, or 9 feet, the wheat fallow soil was estimated to contain only 52.4 pounds of nitrogen as nitric acid per acre, the *Trifolium repens* soil, that is, the leguminous plant soil, contained to the same depth 145.7 pounds. Now, independently of the fact that the leguminous plant plats had received mineral manures and the wheat land had not, the characteristic difference in the history of the two plats was that the one had from time to time grown a leguminous crop and the other had not; and the one which had grown leguminous crops contained, to the depth of 9 feet, nearly three times as much nitrogen as nitric acid as the gramineous crop soil. The difference is the greatest near the surface, but it is very considerable down to the lowest depths. In the first three depths there was more than twice as much nitrogen as nitric acid in the *Trifolium repens* as in the wheat fallow soil; in the second and third three depths there was more than three times, and in the fourth three more than four times as much. Hence, it is obvious that any loss by drainage would be much the greater from the Trifolium plat, so that the difference between the two plats was probably greater than the figures show.

In the case of both plats, the actual amount of nitrogen as nitric acid was the greatest near the surface, indicating more active nitrification; and the greater amount in the Trifolium soil is doubtless due to more

nitrogenous crop residue from the leguminous than from the gramineous crop. Indeed, about 74 pounds per acre of nitrogen had been removed in the *Trifolium repens* crops, and only 18 pounds in the wheat (reckoned on the half acre in crop) in 1882, and none from either in 1883, the year of soil sampling; and the crop residue of the *Trifolium repens* would contain much more nitrogen than that of the wheat. But it is not probable that the excess of nitric acid in the Trifolium soil, together with the larger amount lost by drainage, could be entirely due to the nitrification of recent crop residue. Some found in the lower layers was, however, doubtless due to washing down from the surface. But, as notwithstanding much more nitrogen had been removed in the crops from the leguminous than from the gramineous crop land during the preceding thirty years, the surface soil of the leguminous plat remained slightly richer in nitrogen, it is obvious that the whole of the nitrogen of the nitric acid could not have had its origin in the surface soil. If, therefore, it did not come from the atmosphere, it has been derived from the subsoil.

The indication is that nitrification is more active under the influence of leguminous than of gramineous growth and crop residue. There would not only be more nitrogenous matter for nitrification, but it would seem that the development of the nitrifying organisms is the more favored. Part of the result may, therefore, be due to the passage downward of the organisms and the nitrification of the organic nitrogen of the subsoil. An alternative is that the soil and subsoil may still be the source of the nitrogen, but that the plants may take up, at any rate part, as ammonia, or as organic nitrogen. To this point I shall recur presently.

Comparing the amounts of nitrogen as nitric acid in the *Vicia sativa* soils, with those in the *Trifolium repens* soil it is to be observed that, while from the *Trifolium repens* soil only 164 pounds of nitrogen had been removed per acre in the crops of the five years to 1882 inclusive, 366 pounds had been removed in the Vicia crops to the same date. Then, while none was removed in crops from the Trifolium plat in 1883, 101 pounds were removed in the Vicia crops just before soil sampling. Under these circumstances one of the Vicia soils contained 81.5 pounds and the other 91 pounds less nitrogen as nitric acid per acre than the *Trifolium repens* soil. Of course we can not know exactly how much was at the disposal of the plants at the commencement of growth, but if there had only been as much as in the case of the Trifolium plat it is seen that the deficiency in the Vicia soils nearly corresponds with the amount removed in the crop, which was 101 pounds. It may, at any rate, safely be concluded that most, if not the whole, of the nitrogen of the Vicia crops had been taken up as nitric acid. But, as the Vicia crops had removed much more in the preceding years than the Trifolium crops, so also would their crop residue be greater; and, in fact, much more nitrogen must have been taken up by the plants each year than the figures show, and the larger the crop residue the larger would be the amount of nitric acid for each succeeding crop. But the crop of 1883 was also large, and it would leave a correspond-

ingly large nitrogenous crop residue; leaving, therefore, a large amount of the nitrogen assimilated to be otherwise accounted for than by previous crop residue.

Lastly, in reference to these experiments, it is seen that at each of the twelve depths the Vicia soils with growth contained much less nitric acid than the Trifolium soil without growth; and the difference is much the greatest in the upper four or five depths, within which the Vicia throws out by far the larger proportion of its feeding roots; but the deficiency is quite distinct below this depth. The supposition is that under the influence of the growth water had been brought up from below, and with it nitric acid. In fact, determinations showed that down to the depth of 108 inches the Vicia soils contained less water than the Trifolium soil, in amount corresponding to between 6 and 7 inches of rain, or to between 600 and 700 tons of water per acre.

Experiments of the same kind were again made in 1885. *Trifolium repens* was again selected as the weak and superficially rooting plant, *Melilotus leucantha* as a deeper and stronger rooting one, and the *Medicago sativa* as a still deeper and still stronger rooting plant. Samples of soil were taken at the end of July and the beginning of August from two places on each plat, and in each case, as before, to twelve depths of 9 inches each, or to a total depth of 108 inches, or 9 feet. It will suffice to quote the results for the *Trifolium repens* and the *Medicago sativa* plats. They are given in Table 44.

TABLE 44.—*Nitrogen as nitric acid (per acre, pounds) in the soil and subsoils of some experimental plats without nitrogenous manure for more than thirty years. Hoosfield, Rothamsted.*

[Samples collected July 29 to August 14, 1885.]

Depths.	Series 1, mineral manures.		
	Trifolium repens (plat 5).	Medicago sativa (plat 5).	Medicago sativa + or − Trifolium repens.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*
1–9	11.50	8.88	− 2.62
10–18	1.38	1.11	− .27
19–27	.90	.78	− .12
28–36	1.86	.81	− 1.05
37–45	7.08	.99	− 6.09
46–54	11.31	.93	− 10.38
55–63	13.14	.57	− 12.57
64–72	12.63	.81	− 11.82
73–81	11.19	.70	− 10.49
82–90	10.70	.61	− 10.09
91–99	11.08	.44	− 10.64
100–108	9.96	.41	− 9.55
Total..	102.73	17.04	− 85.69
SUMMARY AND CONTROL.			
1–9	11.50	8.88	− 2.62
10–18	1.38	1.11	− .27
Mixture of 19–108 inches...	88.02	6.97	− 81.05
Total..	100.90	16.96	− 83.94

It is seen that there was much less nitrogen as nitric acid in the *Trifolium repens* soil in 1885, after the removal of 97 pounds in the crops, than in 1883 (see Table 43, p. 113), when there had been no crop. The deficiency is the greatest in the two upper layers; but it extends to the fifth depth, representing the range of the direct and indirect action of the superficial roots. Below this point there is, however, even more than in 1883, due, doubtless, in part to percolation from above during the two preceding seasons without growth, and possibly in part to percolation of the nitrifying organisms and the nitrification of the nitrogen of the subsoil.

Let us now compare the results relating to the *Medicago sativa* with those relating to the *Trifolium repens* soils.

The table of the estimated nitrogen in the produce per acre (p. 111) shows that, from the commencement to 1885, inclusive, the *Trifolium repens* yielded only 261 pounds of nitrogen in crops, but that the Medicago gave 917 pounds. Again, in 1885, the year of soil sampling, the Trifolium gave only 97 pounds, but the Medicago gave 270 pounds. It is further to be observed that, quite accordantly with the usual character of growth of lucerne in agriculture, with the increasing root range, and consequently increased command of the stores of the soil and subsoil, the yield of nitrogen increased from 28 pounds in the first and second years to 337 pounds in the fifth year of growth, declining, however, somewhat afterwards.

Under these circumstances of very large yields of nitrogen in the crops there is at everyone of the twelve depths less, and at most very much less, nitrogen as nitric acid remaining in the soil than where so much less had been removed in the *Trifolium repens* crops. The difference is distinct even in the upper layers; but it is very striking in the lower depths. Thus there is, on the average, not one-twelfth as much nitric nitrogen in the lower ten depths of the soil of the deep-rooting and high nitrogen-yielding *Medicago sativa* as in those of the shallow-rooting and comparatively low nitrogen-yielding *Trifolium repens.* Indeed, the nitric acid is nearly exhausted in the deep-rooting *Medicago sativa* plat, there remaining, to the total depth of 9 feet, only about 17 pounds of nitric nitrogen, against more than 100 pounds to the same depth in the *Trifolium repens* soil. The total deficiency of nitric-nitrogen in the Medicago, as compared with the *Trifolium repens* soil, is seen to be 85.69 pounds according to one set of determinations and 83.94 pounds according to the other.

As already said, we can not know what was the stock of nitric nitrogen on the soil at the commencement of the growth of the season or the amount formed during the growing period. But with so much more Medicago growth for several previous years, it seems reasonable to assume that there would be much more nitrogenous crop residue for nitrification than in the case of the *Trifolium repens* plat. But, even supposing, for the sake of illustration, that each year's growth would

leave crop residue yielding an amount of nitrogen as nitric acid for the next crop, or succeeding crops, approximately equal to the amount which had been removed in the crop, the increasing amounts of nitrogen yielded in the crops from year to year could not be so accounted for, and there would remain the amount of nitrogen in the crop residue itself still to be provided in addition. In fact, assuming the proportion of nitrogen in the crop residue to that in the removed crop to be as supposed in the above illustration, nearly 700 pounds of nitrogen would have been required for the Medicago crop and crop residue of 1884. Or, if we assume the nitrogen in the residue to be only half that in the crop, about 500 pounds would have been required. Doubtless, however, some of the nitrogenous crop residue would accumulate from year to year. The results can leave no doubt that the *Trifolium repens* and the *Medicago sativa* have each taken up much nitrogen from nitric acid within the soil, and that, in fact, nitric acid is an important source of the nitrogen of the Leguminosæ. Indeed, existing direct experimental evidence relating to nitric acid carries us quantitatively further than any other line of explanation. But it is obviously quite inadequate to account for the facts of growth, either in the case of the *Medicago sativa* after the clover or in that of the clover after the beans.

It is obvious that, if nitric acid were the source of the whole, there must have been a great deal formed by the nitrification of the nitrogen of the subsoil. A difficulty in the way of the assumption that nitric acid is the exclusive or even the main source of the nitrogen of the Leguminosæ is that the direct application of nitrates as manure has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as sodium or calcium nitrate, unaccompanied by the other necessary mineral constituents in an available form; whereas, in the case of nitric acid being formed by direct action on the subsoil, it is probable that it will be associated with other constituents, liberated, and so rendered available at the same time.

Numerous direct experiments have been made at Rothamsted to determine whether the nitrogen existing in a comparatively insoluble condition in raw clay subsoil was susceptible of nitrification, and the methods and results have been described in various papers. It was established that the nitrogenous matters of raw clay subsoils, which constitute an enormous store of already combined nitrogen, are susceptible of nitrification if the organisms, with the other necessary conditions, including a sufficient supply of oxygen, are present. It was further indicated not only that the action was more marked under the influence of leguminous than of gramineous growth and crop residue, but that the organisms become distributed to a considerable depth, even in raw clay subsoils, especially where deep-rooted and free-growing Leguminosæ have developed. But the data at command do not justify the conclusion that the

essential conditions would be adequately available in such cases as those of the very large accumulations of nitrogen by the red clover grown after the beans, and of the increasing and very large accumulations by the *Medicago sativa* for a number of years in succession. The alternatives are either that the plant may take up nitrogen from the subsoil in some other way, as ammonia, or as organic nitrogen, or that the free nitrogen of the atmosphere is in some way brought under contribution.

In reference to the first of these alternatives, the question suggested itself whether roots, by virtue of their acid sap, may not either directly take up, or at any rate attack and liberate for further change the otherwise insoluble organic nitrogen of the subsoil. Accordingly, the root sap of many plants was examined, and it was found to be more or less acid, that of the deep, strong, fleshy root of the *Medicago sativa* being very strongly so. The degree of acidity of the juice was determined, and attempts were made so to free the extract from nitrogenous bodies as to render it available for determining whether or not it would attack and take up the nitrogen of the raw clay subsoil. These attempts were, however, unsuccessful.

Experiments were next made to determine the action on soils and subsoils of various organic acids, in solutions of a degree of acidity either approximately the same as that of the *Medicago sativa* root juice, or having a known relation to it. These experiments and their results have been fully detailed elsewhere. It is only necessary to say here that the results did not justify any very definite conclusions as to the probability that the action of roots in the soil, by virtue of their acid sap, is quantitatively an important source of the nitrogen of plants having an extended development of roots, of which the sap is strongly acid. Indeed, although significant indications have been obtained, both as to the importance of nitric acid as a source of the nitrogen of the Leguminosæ, and as to the action of organic acids in rendering soluble the otherwise insoluble nitrogenous compounds of soils and subsoils, yet on neither of these points is the evidence at present available adequate to account satisfactorily for the facts of growth.

Lastly, in regard to the sources of already combined nitrogen available to our crops, the evidence points to the conclusion that, independently of the small amount of combined nitrogen annually coming from the atmosphere in rain, and the minor aqueous deposits, the source of the nitrogen, at any rate of most of our crops, is the stores already existing within the soil and subsoil, or those provided by manure. It has further been seen that the combined nitrogen is largely taken up as nitric acid, or rather as nitrates. But it is nevertheless obvious that we have yet to seek for an explanation of the source of the whole of the nitrogen of the Leguminosæ.

We are brought to inquire, therefore, What is the evidence relating to the question of the *fixation of free nitrogen*, by the plant, by the soil, or otherwise?

EVIDENCE AS TO FIXATION OF FREE NITROGEN.

It can hardly be said that there remains an unsolved problem in the matter of the sources of the nitrogen of our nonleguminous crops of wheat, of barley, and of grasses, as representatives of the great natural order of the Gramineæ; of turnips, representing the Cruciferæ; of some varieties of beet, representing the Chenopodiaceæ, and of potatoes, of the Solanaceæ. It must be admitted to be quite otherwise so far as our leguminous crops are concerned.

It is nearly a century since the question whether plants took up, or evolved, free nitrogen, became a matter of experiment and of discussion, and it is more than half a century since Boussingault commenced experiments to determine whether plants assimilate free nitrogen. From his results he concluded that they did not; and those obtained at Rothamsted more than thirty years ago confirmed the conclusions of Boussingault. In fact, we concluded that under the conditions of those experiments, which were those of sterilization and inclosure, in which, therefore, the action both of electricity and of microbes was excluded, the results were conclusive against the supposition that, under such condition, the higher chlorophylious plants can directly fix free nitrogen, either by their leaves or otherwise. It may, in fact, be concluded that, at any rate, in the case of our gramineous, our cruciferous, our chenopodiaceous, and our solanaceous crops, free nitrogen is not the source. Nevertheless, we have long admitted that existing evidence was insufficient to explain the source of the whole of the nitrogen of the Leguminosæ; that there was, in fact, a missing link!

Limiting the discussion here mainly to the question of the sources of the nitrogen of the Leguminosæ, it is generally admitted that all the evidence that has been acquired on lines of inquiry until recently followed has failed to solve the problem. During the last few years, however, the discussion has assumed a somewhat different aspect.

The question still is, whether free nitrogen is an important source of the nitrogen of vegetation generally, but especially of the Leguminosæ; but while few now assume that the higher chlorophyllous plants directly assimilate free nitrogen, it is nevertheless supposed to be brought under contribution in various ways; but especially by being brought into combination under the influence of microorganisms, or of other low forms, either within the soil itself, or in symbiotic growth with a higher plant.

Professor Atwater made numerous experiments both on the germination and on the growth of peas. In eleven out of thirteen experiments on germination, more or less loss of nitrogen was observed. In all but one, out of fifteen experiments on vegetation there was a gain of nitrogen, which was very variable in amount and sometimes very large. As a general conclusion, he states that in some of the experiments half or more of the total nitrogen of the plants was acquired from

the air. He considered that germination without loss of nitrogen was the normal process; that loss, whether during germination or growth, was due to decay, and therefore only accessory. He, however, goes into calculation of some of his own results, showing by the side of the actual gains the greater gains, supposing there had been a loss of 15 per cent of nitrogen, and the still greater gains if there had been a loss of 45 per cent, as in an experiment by Boussingault under special conditions. Further, he says that while actually-observed gains are proof of the acquisition of nitrogen, the failure to show gain only proves nonfixation, if it be proved that there was no liberation. He suggests that the negative results obtained by Boussingault and at Rothamsted may be accounted for by liberation; though he recognizes that the conditions of the experiments excluded the action of either electricity or microbes. It may be remarked that, in the experiments both of Boussingault and at Rothamsted, any cases of decay were carefully observed, and the losses found explained accordingly. It may, in fact, be taken as certain that the conclusions drawn were not vitiated by any such loss.

Atwater concluded that his results did not settle whether the nitrogen gained was acquired as free or combined nitrogen by the foliage or by the soil. He considered, however, that in his experiments the conditions were not favorable for the action either of electricity or of microorganisms, and he favored the assumption that the plants themselves were the agents. Lastly, he considered the fact of the acquisition of free nitrogen in some way to be well established, and that thus facts of vegetable production are explained which otherwise would remain unexplained. To this and other points involved I shall refer again presently.

Of all the recent results bearing upon the subject those of Hellriegel and Wilfarth with certain leguminous plants seemed to be by far the most definite and significant, pointing to the conclusion that, although the higher chlorophyllous plants may not directly utilize free nitrogen, some of them, at any rate, may acquire nitrogen brought into combination under the influence of lower organisms, the development of which is apparently in some cases a coincident of the growth of the higher plant whose nutrition they are to serve.

It was in the agricultural chemistry section of the Naturforscher Versammlung held in Berlin in 1886, when I happened to be presiding, that Professor Hellriegel first announced his new results. Quite consistently, not only with common experience in agriculture, but also with the direct experimental results of ourselves and others, Hellriegel found that plants of the gramineous, the chenopodiaceous, the polygonaceous, and the cruciferous orders depended on combined nitrogen supplied within the soil. On the other hand, he found that leguminous plants did not depend entirely on such supplies. His results were indeed not only very definite, but it is seen that they had

a special bearing on the admittedly unsolved problem of the source of the whole of the nitrogen of leguminous crops.

In the case of these plants—that of peas, for example—it was observed that in a series of pots to which no nitrogen was added most of the plants were apparently limited in their growth by the amount of nitrogen which the seed supplied. Here and there, however, a plant growing under ostensibly the same conditions grew very luxuriantly, and on examination it was found that whilst no nodules were developed on the roots of the plants of limited growth, they were abundant on those of the luxuriantly grown plants.

In view of this result Hellriegel, with his colleague, Dr. Wilfarth, instituted experiments to determine whether, by the infection of the soil with appropriate organisms, the formation of the root nodules and luxuriant growth could be induced; and whether, by the exclusion of such infection, the result could be prevented. To this end, they added to some of a series of experimental pots 25 or 50 cubic centimeters of the turbid, watery extract of a fertile soil, made by shaking a given quantity of it with five times its weight of distilled water, and then allowing the solid matter to subside. In some cases, however, the extract was sterilized. In those in which it was not sterilized there was almost always luxuriant growth and abundant formation of root nodules; but with sterilization there was no such result. Consistent results were obtained with peas, vetches, and some other Leguminosæ; but the same soil extract had little or no effect in the case of lupines, serradella, and some other plants of the family, which are known to grow more naturally on sandy than on loamy or rich humus soils. Accordingly, they made a similar extract from a diluvial sandy soil, where lupines were growing well, in which, therefore, it might be supposed that the organism peculiar to such a soil would be present; and on the application of this to a nitrogen-free soil, lupines grew in it luxuriantly and nodules were abundantly developed on their roots.

Further particulars of the experiments of Hellriegel and Wilfarth, and also of the results and conclusions of Berthelot, Dehérain, Joulie, Deitzell, Frank, Emil von Wolff, and Atwater, as well as some of the later experiments of Boussingault which have a bearing on the present aspect of the question, will be found in our paper published in 1889.[1] A short account is also given of the experiments of Bréal, in our paper published in 1890.[2] It may be added that A. Petermann found gain with lupines, but doubted whether it was entirely due to root-nodule action, or whether it was from the combined or the free nitrogen of the air.[3]

Thus, then, not only did Hellriegel and Wilfarth get negative results with plants of other families than the Leguminosæ, as all experience would lead us to expect, but they obtained positive results with

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[1] Phil. Trans. vol. 180 (1889) B.

[2] Proc. Roy. Soc., vol. 47, 1890.

[3] Bull. Stat. Agron. Gembloux, Belg., March, 1890.

the Leguminosæ in regard to the source of the whole of the nitrogen, of which experience showed that there was a "missing link." Such results were obviously of fundamental and of far-reaching importance, and it seemed desirable that the subject should be further investigated with a view to their confirmation or otherwise. Accordingly it was decided to take it up at Rothamsted, and it was hoped to commence experiments in 1887, but it was not possible to do so until 1888. In that year a preliminary series was undertaken, and the investigation has been continued each year since, and is, in fact, not yet completed.

I propose to give a brief account of the conditions, and of the results of these recent experiments made at Rothamsted, which do show a fixation of free nitrogen. But before doing so it will be well to call attention to those of the earlier experiments which did not indicate any fixation, as the well defined difference in the conditions under which such different results were obtained will bring clearly to view what are the conditions under which fixation does, and what are those under which it does not, take place.

EARLIER EXPERIMENTS WHICH DID NOT SHOW FIXATION OF FREE NITROGEN.

Experiments on the subject were commenced at Rothamsted in 1857, they were continued for several years, and the late Dr. Pugh took a prominent part in the inquiry.

The soils used were ignited, washed, and reignited pumice or soil. The specially made pots we ignited before use and cooled over sulphuric acid under cover. Each pot with its plants was inclosed under a glass shade, which rested in the groove of a specially made hard baked glazed stoneware lute vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soil, and there was an outlet at the bottom of the lute vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure. A stream of water being allowed to flow from a tank into a large stoneware Woulff's bottle of more than 20 gallons capacity, the air passed from it by a tube, through two small glass Woulff's bottles containing sulphuric acid, and then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Woulff's bottle containing a saturated solution of ignited carbonate of soda; and, after being so washed, the air entered the glass shade, from which it passed by the exit tube through an eight-bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air was prevented. Carbonic acid was supplied as required by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas passing through one of the bottles of sulphuric acid, through the long tube, and through

the carbonate of soda solution before entering the shade. In 1857 twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute vessels and shades; in 1859 six, and in 1860 also six. Each year the whole were arranged side by side on stands of brickwork in the open air.

The numerical results obtained in the experiments of 1857 and 1858 are summarized in Table 45.

TABLE 15.—*Summary of the results of experiments made at Rothamsted, in 1857 and 1858, to determine whether plants assimilate free nitrogen.*

	Nitrogen.		
	In seed and manure, if any.	In plants, pot, and soil.	Gain or loss.
WITH NO COMBINED NITROGEN SUPPLIED BEYOND THAT IN THE SEED SOWN.			
Gramineæ:			
1857—	*Gram.*	*Gram.*	*Gram.*
Wheat	0.0080	0.0072	−0.0008
Barley	.0056	.0072	+ .0016
Barley	.0056	.0082	+ .0026
1858—			
Wheat	.0078	.0081	+ .0003
Barley	.0057	.0058	+ .0001
Oats	.0063	.0056	− .0007
1858 *a* [1]—			
Wheat	.0078	.0078	.0000
Oats	.0064	.0063	− .0001
Leguminosæ:			
1857—			
Beans	.0796	.0791	− .0005
1858—			
Beans	.0750	.0757	+ .0007
Peas	.0188	.0167	− .0021
Other plants, 1858, buckwheat	.0200	.0182	− .0018
WITH COMBINED NITROGEN SUPPLIED BEYOND THAT IN THE SEED SOWN.			
Gramineæ:			
1857—			
Wheat	.0329	.0383	+ .0054
Wheat	.0329	.0331	+ .0002
Barley	.0326	.0328	+ .0002
Barley	.0268	.0337	+ .0069
1858—			
Wheat	.0548	.0536	− .0012
Barley	.0496	.0464	− .0032
Oats	.0312	.0216	− .0096
1858 *a* [1]—			
Wheat	.0268	.0274	+ .0006
Barley	.0257	.0242	− .0015
Oats	.0260	.0198	− .0062
Leguminosæ:			
1858—			
Peas	.0227	.0211	− .0016
Clover	.0712	.0665	− .0047
1858 *a* [1]—			
Beans	.0711	.0655	− .0056
Other plants, 1858, buckwheat	.0308	.0292	− .0016

[1] These experiments were conducted in the apparatus of M. G. Ville.

The upper part of the table shows the results obtained, in 1857 and 1858, in the experiments in which no combined nitrogen was supplied beyond that contained in the seed sown. The growth was extremely restricted under these conditions, and the figures show that neither with the Gramineæ, the Leguminosæ, nor the Polygonaceæ (buckwheat), was there in any case a gain of 3 milligrams of nitrogen. In most cases there was much less gain than this, or a slight loss. There was, in fact, nothing in the results to lead to the conclusion that either of these different descriptions of plant had assimilated free nitrogen.

The lower part of the table shows the results obtained in the experiments in which the plants were supplied with known quantities of combined nitrogen, in the form of a solution of ammonium sulphate applied to the soil. The effect of this direct supply of combined nitrogen was to increase the growth in a very marked degree, especially in the case of the Gramineæ. The figures show that the actual gains or losses of nitrogen ranged a little higher in these experiments in which larger quantities were involved; but they were always represented by units of milligrams only, and the losses were higher than the gains. Further, the gains, such as they were, were all in the experiments with the Gramineæ, whilst there was, in each case, a loss with the Leguminosæ, and also with the buckwheat. The losses, where beyond the limits that might be expected from experimental error, properly so called, were doubtless due to decay of organic matter, fallen leaves, etc.

It should be stated that the growth was far more healthy with the Gramineæ than with the Leguminosæ, which are, even in the open field, very susceptible to vicissitudes of heat and moisture, and were found to be extremely so under the conditions of inclosure under glass shades. It might be objected, therefore, that the negative results with the Leguminosæ are not so conclusive as those with the Gramineæ. Nevertheless we concluded, and still conclude, from the results of our own experiments, as Boussingault did from his, that neither the Gramineæ nor the Leguminosæ directly assimilate the free nitrogen of the air.

That, under the conditions described, the Leguminosæ as well as the Gramineæ can take up and assimilate already combined nitrogen supplied to them, is clearly illustrated in the experiments made in 1860 with Leguminosæ alone. The series comprised three experiments with white haricot beans; No. 1 without any other supply of combined nitrogen than that in the seed, No. 2 with a fixed quantity of nitrogen applied as ammonium sulphate, and No. 3 with a fixed quantity supplied as nitrate; also three experiments with white lupines; No. 1, as with the haricots, without artificial supply of combined nitrogen, No. 2 with supply as ammonium sulphate, and No. 3 as nitrate. Each of these two descriptions of leguminous plant showed considerably increased growth under the influence both of ammonium sulphate and of nitrate. Indeed, the growth was much more satisfactory than in the earlier experiments. Still, owing to the atmospheric conditions within the shades, the plants lost both leaves and flowers, and were, therefore, taken up earlier than they otherwise would have been. The analytical results here again indicated no gain from free nitrogen, either in the experiments without or in those with an artificial supply of combined nitrogen. In fact, the losses were greater than the gains.

Such, then, were the negative results obtained when plants were grown under conditions of sterilization and of inclosure. There was, under such conditions, no gain from free nitrogen in the growth of either Gramineæ, Leguminosæ, or other plants.

RECENT EXPERIMENTS WHICH DO SHOW FIXATION OF FREE NITROGEN.

It was about the year 1876 that M. Berthelot called in question the legitimacy of the conclusion that plants do not assimilate the free nitrogen of the air when drawn from the results of experiments in which the plants are so inclosed as to exclude the possibility of electrical action; and later he objected to experiments so conducted with sterilized materials, on the ground that under such conditions the presence, development, and action of microorganisms are excluded. So far, however, there is nothing in the recent results, either of M. Berthelot himself or of others, which can be held to invalidate the conclusion which had been drawn from the results of Boussingault and from those obtained at Rothamsted, *that the higher chlorophyllous plants do not directly assimilate free nitrogen.*

Let us now consider what are the results obtained when the conditions of growth involve neither sterilization nor inclosure.

A preliminary series of experiments was commenced in 1888, and a more systematic one in 1889. The plants were grown in specially made pots, and arranged in a glass house.

In 1888 peas, blue lupines, and yellow lupines were grown, and there were four pots of each: (1) With washed sand and the ash of the plant added, but no supply of combined nitrogen beyond a small determined amount in the washed sand and that in the seed sown; (2) with similarly prepared sand (and ash), but microbe seeded with the turbid watery extract from a rich garden soil; (3) duplicate of No. 2; (4) with the rich garden soil itself. There was, under the influence of soil extract microbe seeding, considerable formation of nodules on the roots, and considerable gain of nitrogen.

In 1889, as already said, a more extended series was commenced. It included experiments with four annuals, namely, peas, beans, vetches, and yellow lupines; also with four plants of longer life—white clover, red clover, sainfoin, and lucern. And, as will be seen further on, experiments were commenced in 1890 with the same four annuals and the same four plants of longer life, on somewhat different lines from those above referred to.

Referring to the experiments in the glass house, it may be stated that in 1889 and subsequently a purer white sand was used, which was washed and sterilized by heat. The ash of the plant and a small quantity of calcium carbonate were added.

There were four pots of each description of plant, excepting in the case of the white clover, of which there were five. For the peas, vetches, beans, white clover, red clover, sainfoin, and lucern, one was with the prepared quartz sand, without soil extract; two others were with the quartz sand and garden soil extract added, and the fourth was with the garden soil itself, the fifth pot of white clover receiving calcium nitrate instead of soil extract. Of the lupines (blue and yellow) No. 1 was

with the prepared quartz sand, without soil extract; Nos. 2 and 3 were with lupine soil extract added, and No. 4 was with the lupine sandy soil itself, to which 0.01 per cent of the plant ash was added.

The analytical details relating to the experiments commenced in 1889 and subsequently, though now completed, have not yet been published, so that numerical results can not be given here. The following general statement of their bearing will, however, convey a clear idea of their significance and their importance.

Fig. 1.—Peas grown in experiments on the fixation of free nitrogen.

First, as to the peas. There was limited growth in pot 1, with sand without soil extract, and there was an entire absence of nodule formation on the roots. The increased growth in pots 2 and 3, with soil extract, was coincident with a very great development of nodules.

In pot 4, with garden soil itself supplying abundance of combined nitrogen and doubtless microorganisms as well, there was also a considerable development of nodules, but distinctly less than in either pot 2 or pot 3 with sand and soil extract only. Lastly, without soil extract

and without nodules there was no gain of nitrogen, but with soil extract and with nodule formation there was much gain of nitrogen, there being many times as much in the products of growth as in the seed sown. For illustration of the above-ground growth see fig. 1, p. 126.

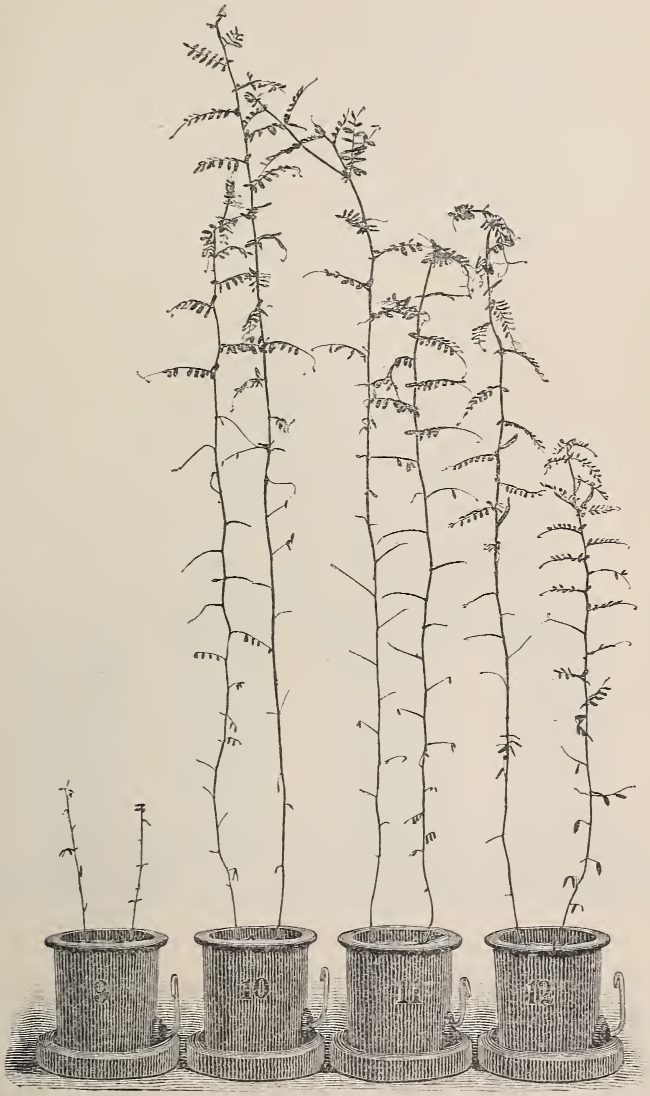

FIG. 2.—Vetches grown in experiments on the fixation of free nitrogen.

With the vetches, as with the peas, there was very restricted above-ground growth without soil extract seeding (No. 9), and this was associated with very limited root development, and with the entire absence of nodule formation. On the other hand, the greatly extended vegetative growth with soil extract (Nos. 10 and 11), was associated

with an immense development of root and root fiber, and with the formation of numerous nodules. Again, in the garden soil (No. 12), with its liberal supply of combined nitrogen as well as microorganisms, there was much less development of roots and less also of nodules than in the pots with sand and soil extract only. Further, without microbe seeding and with no nodules there was no gain of nitrogen, while with microbe seeding and with numerous nodules there was considerable gain of nitrogen, there being, with much less nitrogen in the seed and about the same amount in the products as in the corresponding experiments with peas, very many times as much nitrogen in the vegetable matter produced as in the seed sown. (See fig. 2, p. 127.)

The experiments with yellow lupines gave very striking results. As with the other plants, sterilized sand with ash was used in pots 17, 18,

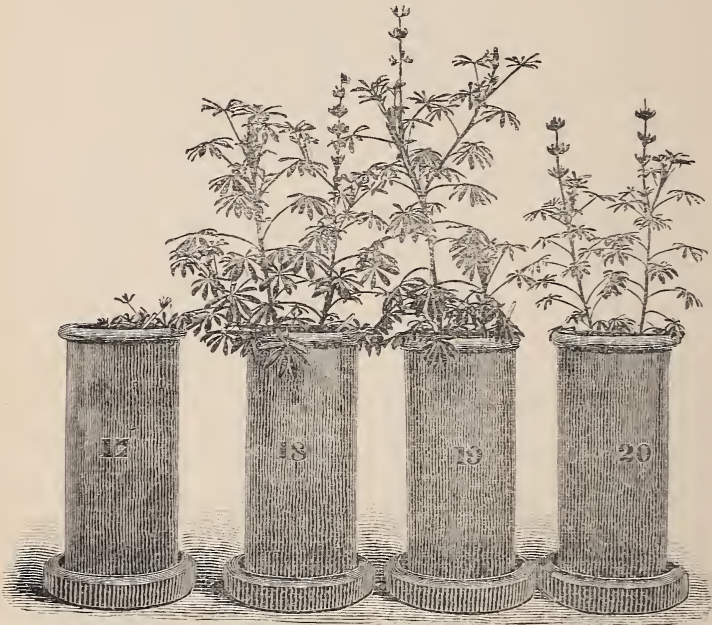

FIG. 3.—Lupines grown in experiments on the fixation of free nitrogen.

and 19, but pot 20 was filled with sandy soil from a field where lupines were growing. Pot 17 was left without microbe seeding, but pots 18 and 19 were microbe seeded by a watery extract of the lupine soil, instead of garden soil, as in the other cases. The results with the yellow lupines were as follows: In the sterilized quartz sand, without microbe seeding, the growth was extremely limited, both above and under ground. Under the influence of the lupine soil extract seeding the above-ground growth was not only very luxuriant, but the plants developed considerable maturing tendency, flowering and seeding freely. The development of the roots generally and that of swellings, or nodules, on them was also very marked. In pot 20, with the lupine sand itself, which

would supply a not immaterial amount of combined nitrogen, although the growth was fairly normal, it was, both above ground and within the soil, much less than in the pots with sand and the soil extract only, and the development of nodules was also less. It was concluded that the less growth in the lupine sand itself than in the quartz sand with the lupine soil extract was largely due to the much less porosity of the lupine soil, especially when watered. (See fig. 3, p. 128.)

Again, as with the peas and vetches, so with the lupines, without microbe seeding there was very limited growth, no formation of nodules, and no gain of nitrogen, but with microbe seeding there was luxuriant growth, abundant nodule formation, and, coincidently, great gain of nitrogen. There was, in fact, very many times as much nitrogen in the products of growth as in the seed sown.

In the experiments with the fourth annual, the beans, the plants suffered much from aphis; the growth was consequently very limited, and the gain of nitrogen but small.

The results with peas, vetches, and yellow lupines are, however, very definite and very striking. They are abundantly illustrative of the fact that under the influence of suitable microbe seeding of the soil there is nodule formation on the roots, and, coincidently, increased growth and gain of nitrogen beyond that supplied in the soil and in the seed as combined nitrogen, presumably due to the fixation, in some way, of free nitrogen. On this point it may be observed that MM. Schloesing fils and Laurent have shown, by growing Leguminosæ in closed vessels and by the analysis of the air before and after growth, that free nitrogen disappeared in quantity closely corresponding to that gained in growth, thus establishing the fact that the source of the gain was free nitrogen.[1]

As already said, experiments were also made with four plants of longer life—white clover, red clover, sainfoin, and lucern.

The white clover was sown in July, 1890. Pot 1 was with sand and ash without microbe seeding; pots 2 and 3, the same, with microbe seeding; pot 4, with garden soil, and pot 5, with sand and ash, sterilized, but with calcium nitrate added. Pot 1 gave no cutting, but pots 2, 3, 4, and 5, each gave many cuttings; and the plants were not taken up until December, 1892. On the roots of the plants in pot 1, without microbe seeding, there were no nodules, and there was extremely limited growth. On those in pots 2 and 3, with microbe seeding, there were many nodules, and in each case the produce contained several hundred times as much nitrogen as that in pot 1. There was obviously, therefore, great gain. The plants grown by the nitrate also contained several hundred times as much nitrogen as those in pot 1, but there were no nodules on the roots.

The red clover was sown in July, 1889, yielded many cuttings, and was not taken up until the winter of 1890–91. Pot 1, without soil-extract seeding, obviously became accidentally microbe seeded; the

[1] Compt. Rend., 111, p. 750.

growth was considerable, there were nodules on the roots, and there was considerable gain. There was also much nodule formation, and there was great gain of nitrogen under the influence of the soil-extract seeding; but less than in the case of the white clover.

The sainfoin was sown in June, 1890, and the growth was very limited; supposed to be accounted for by imperfect microbe infection of the roots, and the gain was accordingly but small.

The lucern grew much better than the sainfoin, the roots were much more infected by the microbe seeding, and there was accordingly considerable gain of nitrogen.

In reference to the failure of growth in the cases where it was apparently due to failure to obtain suitable microbe infection, it has already been said that Hellriegel at first found great difficulty in insuring a good result with lupines, serradella, and some other plants, among which was red clover; and the failure to obtain good results at Rothamsted with both blue and yellow lupines in 1888, and with blue lupines in 1889, was doubtless partly due to the same cause.

As bearing upon this curious and interesting point, it will be well briefly to refer here to the experiments and results of Professor Nobbe on this subject.[1] He undertook an investigation to determine whether leguminous trees, as well as our agricultural leguminous plants, were susceptible to microbe infection and nodule formation; and also to ascertain whether there is one nodule-forming bacterium, or whether many bacteria have the property—each description of plant, or perhaps each group, having its special bacterium.

The plants he experimented upon were peas, yellow lupines, and beans; also as trees, *Robinia pseudacacia* (locust tree), *Cytisus laburnum* (laburnum), and *Gleditschia triacantha* (honey locust). To each of these he applied microbe seeding from various sources, in some cases only soil extracts, and in others pure cultivations, either from soil extracts or from the root nodules of different plants. When soil extracts only were used the results were somewhat irregular. But when pure cultivations were employed, the general result was that more effect was produced on any particular description of plant by the bacteria obtained from the same description than by those derived from other descriptions. Nobbe concluded that the results can leave no doubt that the pea and the Robinia bacteria have different physiological actions; which indicate, if not different species or varieties, at any rate different race or nutrition modifications. Beyerinck also concluded that the various papilionaceous bacteria differ more than he had formerly supposed.

Of the three descriptions of leguminous trees upon which Nobbe experimented, the Robinia and the Cytisus, which are both of the papilionaceous subdivision of the leguminous order, were suscepti-

[1] Versuche uber die Stickstoff Assimilation der Leguminosen. F. Nobbe, E. Semid, L. Hiltner, E. Hotter, Landw. Vers. Stat., 39, p. 327.

ble to microbe infection and nodule formation on their roots, and showed, coincidently, gain of nitrogen; but the Gleditschia, which is not papilionaceous, but of the suborder Cæsalpinieæ, was quite indifferent to such infection, although both soil extracts and pure cultivations from various sources were tried. On the other hand, it was found that the application of calcium nitrate and ammonium sulphate gave considerably increased growth. Nobbe observes that the roots of Gleditschia have a very thick covering, which it would be at any rate difficult for the bacteria to penetrate; but whether the members of this group generally behave differently from the Papilionaceæ in this respect remains for future investigation to determine. It is, at any rate, of interest to note that the only leguminous plant outside the papilionaceous suborder which has yet been experimented upon has not been found susceptible to infection, or to have nodules on its roots.

In 1891 F. Nobbe, E. Schmid, L. Hiltner, and E. Hotter commenced various experiments to ascertain the physiological meaning of the root nodules of various nonleguminous plants (Elæagnus, Hippophæ, and Alnus). Elæagnus sprouts were planted in two pots containing sterilized nitrogen-free sand. A week afterwards one pot was infected with an extract of Elæagnus soil. The infection had no visible effect during the whole summer, but in the autumn one of the plants began to acquire a somewhat fresher green color than the others, and in the spring of the following year this plant was unmistakably more vigorous than the others; it was strong and had side shoots. All the plants (of both pots) were isolated in nitrogen-free sand, when it was seen that only the plant which was benefited by the inoculation had nodules. The noninfected plants were scanty and without side shoots. Only one of the infected plants began to get greener in July, 1892; it had three small oblong nodules when taken up.

There was no doubt that Elæagnus was enabled by the possession of nodules to utilize free atmospheric nitrogen. The organisms which produce these nodules were obtained in pure cultivations and were totally different from *Bacterium radicicola.*

Here, then, we have experimental evidence of gain of nitrogen by a nonleguminous plant, but only with the coincidence of nodule development on the roots.

The conclusion drawn from the experiments of Nobbe, that there are various nodule-forming bacteria, is at any rate consistent with the descriptions which have been published as to the difference in the external appearance and the distribution of the root nodules in the case of the peas, the vetches, and the lupines grown at Rothamsted.

Again, the nodules on the roots of lucern growing in the field were observed at different periods of the season in 1887, and again more recently on plants taken from the field for that purpose; and they are quite different in general external character from those on any other plants that have been examined at Rothamsted.

Among the Leguminosæ growing in the mixed herbage of grass land in 1868 nodules were observed on the root fibers of *Lathyrus pratensis*, especially near the surface of the soil; on the ultimate root fibers of *Trifolium pratense*, and on the smaller rootlets of *Trifolium repens*. In the case of red clover growing in rotation on arable land an abundance of nodules has been found, both near the surface and at a considerable depth. They are generally more or less globular or oval. Some found on the main roots were more like "swellings" than attached turbercles, not, however, incasing the root, but only on one side. The greater number are, however, small and chiefly distributed on the root fibers. Again, on the plat of rich garden soil on which red clover has now been grown at Rothamsted for forty years in succession very numerous nodules, chiefly globular and small, have been found on the roots, for the most part within the first few inches of soil, but some to the depth of a foot or more, diminishing, however, very much both in number and in size as the clayey subsoil was reached.

Obviously much more evidence than is at present at command is needed in regard to any difference in character or relative prevalence at different periods in the life and growth of the plant and under different conditions of soil, both so far as mechanical state and porosity and richness or otherwise in available supplies of combined nitrogen are concerned, before any clear conception can be attained of the connection between nodule formation, luxuriance of growth, and gain of nitrogen. The subject in various aspects is being further investigated at Rothamsted, and some of the results so far obtained will be briefly referred to presently.

HOW IS THE FIXATION OF NITROGEN TO BE EXPLAINED?

Reviewing the whole of the results which have been brought forward, there can be no doubt that the fact of the fixation of free nitrogen in the growth of Leguminosæ under the influence of suitable microbe infection of the soil, and of the resulting nodule formation on the roots, may be considered as fully established. How, then, is it to be explained? Unfortunately there is much yet to learn before a satisfactory answer can be given. Obviously we must know more of the nature and mode of life of the organisms which, in symbiosis with the leguminous plant, bring about the fixation of free nitrogen before the nature of the action can be understood. As to the mode of life of these bodies, we owe much to the investigations of Marshall Ward, Prazmouski, Beyerinck, and others, and some of their results have been discussed in our papers. But the facts which they have established so far are insufficient to afford an adequate explanation of the phenomena involved. Nobbe also has recently published results on the subject.

It has, indeed, been assumed that the activity of the process depends on the quantity of the nitrogenous compounds at the disposal of the roots, a supposition which implies that the source of nitrogen of the

bacteria is the combined nitrogen in the soil. The experimental results which have been described clearly show, however, that the nodules may develop very plentifully in a nitrogen-free soil, and that there may, under such conditions, be great gain of nitrogen if only the soil be suitably infected. Nor would there be any such actual gain of nitrogen in nitrogen-free soils, as there undoubtedly is, if the source of the nitrogen, either of the parasite or of the host, were essentially the supplies of combined nitrogen within the soil.

Further, one assumption is that the organisms become distributed in the soil both during the life of the host and afterwards, and that the fixation takes place under their agency within the soil itself rather than in the course of the development of the organisms in symbiosis with the higher plant. Another is, that the fixation takes place in the soil itself under the influence of microbes existing within it, and that the higher plant assimilates the resulting combined nitrogen. As bearing upon these points, it may be observed that in the experiments with peas in 1888 there was practically no gain of nitrogen within the soil itself, which it may be supposed there would have been if the fixation had taken place within it and the host had acquired its gain from the compounds there produced. Indeed, the evidence at present at command certainly does not point to the conclusion that the gain of nitrogen by Leguminosæ under the influence of microbe infection of the soil and nodule formation is due to fixation by organisms within the soil itself independently of the symbiosis. It is obvious, too, that, so far as free nitrogen may be fixed by microbes within the soil independently of connection with a higher plant, the resulting nitrogenous compounds should directly or indirectly be available to plants generally, whether leguminous or nonleguminous. On this point it may be remarked that from the results of vegetation experiments made by Boussingault in 1858 and 1859 in mixtures of rich soil and sand, he concluded that free nitrogen had been fixed within the soil by the agency of mycodermic vegetation, and that the nitrogenous products which remained within it were largely in the form of organic detritus. Subsequently, however, he considered that there was not satisfactory evidence that free nitrogen is fixed within the soil under the influence of the development of the lower organisms. It is, nevertheless, of interest to observe that those of his results in 1858 and 1859 which showed any material gain of nitrogen, either in the vegetable matter grown or in the soil, were obtained with Leguminosæ, and that, in the case in which there was the greatest gain in the plants themselves he records that there were numerous tubercles on their roots. In one other case, in which, however, only sand was used as soil and the gain in the plant was but small, he also observed tubercles on the roots. It is, at any rate, very significant, when viewed in the light of recently-acquired knowledge, that in all the cases of gain the plants grown were of the leguminous family, and that in some of them nodules were observed on the roots.

Again, Berthelot's experiments showed fixation of free nitrogen by the agency of microbes within the soil, both in the absence of higher vegetation, and also coincidently with the growth of nonleguminous plants. He further considered that such fixation takes place to an extent which would be an important source of nitrogen to our crops. As referred to above, Boussingault's experiments of 1858 and 1859 showed fixation within the soil, which he then attributed to the agency of mycodermic vegetation. The fact of such fixation within the soil, under the influence of lower plants, has also been confirmed by the recent results of some other experimenters. Thus, MM. Schloesing fils and Laurent have shown fixation in bare soil, and in soils growing various nonleguminous plants when certain lichens and algæ were developed, but not when their occurrence was prevented. Hellriegel has also found fixation coincidently with the growth of certain algæ. Nevertheless, it may be observed that neither experience in practical agriculture nor the nitrogen statistics of soils and crops points to the conclusion that there is gain of nitrogen to any material extent by the fixation of free nitrogen under the agency of microbes within the soil independently of leguminous growth. It was our intention to commence experiments on this subject at Rothamsted in 1891, but we have not yet been able to do so.

In 1888, however, Berthelot made numerous experiments with Leguminosæ, and in many of them he found very large gains of nitrogen; indeed, a much higher range of gain than in his other experiments. That there should be large gain under such conditions is quite consistent with the results which have been recorded of the experiments made at Rothamsted with Leguminosæ, and with those previously obtained by Hellriegel and Wilfarth. Further, these results of Berthelot, like those obtained at Rothamsted and by others with leguminous plants, are consistent with well established facts of agricultural production, and with the nitrogen statistics of soils and crops, and serve, with them, to aid the solution of long-recognized problems in connection with the growth of leguminous crops.

But, whether or not it may eventually be established that nitrogen is fixed, to any material extent, by microbes within the soil, independently of leguminous growth, there is evidence that in soils and subsoils containing organic nitrogen lower organisms may serve the higher plants by taking up or attacking and bringing into a more readily available condition combined nitrogen not otherwise, or only very slowly, available for the higher plants. For example, it is probable that fungi generally derive nitrogen from organic nitrogen; and in the case of those of fairy rings there can be little doubt that they take up from the soil organic nitrogen which is not available to the meadow plants, and that on their decay their nitrogen becomes available to the associated herbage. Then, in the case of the fungus mantle observed by Frank on the roots of certain trees, it may be supposed that the

fungus takes up organic nitrogen, and so becomes the medium of the supply of the soil nitrogen to the plant. More pertinent still is the action of the nitrifying organisms in rendering the organic nitrogen of the soil and subsoil available to the higher plants. It may well be supposed, therefore, that there may be other cases in which lower organisms may serve the higher, bringing into a more available condition the combined nitrogen already existing, but in a comparatively inert state, in soils and subsoils.

It may, then, be considered as fully established that various Leguminosæ acquire a considerable amount of nitrogen by the fixation of free nitrogen under the influence of the symbiotic growth of their root nodule microbes, and the higher plant; that there is also fixation to some extent, but quantitatively of much less importance, by microbes within the soil; and that there is fixation to some, but to a comparatively immaterial amount, by lower vegetation, such as fungi, lichens, and some algæ. Further, it is established that there is gain from free nitrogen in the case of some nonleguminous higher chlorophyllous plants—Elæagnus, for example—but, as in the case of the Leguminosæ, with the coincidence of root nodule microbe development. There still remains the question whether there is any fixation by the higher chlorophyllous plants themselves independently of the associated growth of lower organisms. Frank maintains that there is such fixation by various nonleguminous plants. In 1892 A. Petermann published the result of experiments with barley in which he found gain of nitrogen which he attributed to fixation by the plant. He at the same time observed that the surface of the soil was partially covered with algæ. In 1893 he published the results of further experiments in which he grew barley both with and without sterilization. He found no gain with sterilization, and attributed that shown without it to the lower vegetation with which the surface of the sand was more or less covered. He concluded that barley is not able to fix free nitrogen, but that soils covered with lower vegetation become richer in nitrogen. He considered that the gain in his earlier experiments was not due, as he then supposed, to fixation by the barley itself, but was brought about by the algæ growing on the surface of the sand. His conclusion was that free nitrogen is not fixed either by the higher plants or by soil free from lower vegetation. Liebscher, from the results of an elaborate series of experiments with various plants, including white and black mustard, concluded that these cruciferous plants have the power of fixing the free nitrogen of the air, but whether with or without the cooperation of soil organisms he considers was not proved. Lotsy, on the other hand, from the results of experiments with the same plants, concludes that there is no such fixation with sterilization, and that it is uncertain whether it takes place under unsterilized conditions. The question is one of practical as well as scientific interest, as these plants are among those grown for green manuring.

Liebscher's experiments certainly appear to have been conducted with very great care under the conditions selected. Nevertheless, it is difficult to accept so important a conclusion from the results of experiments, in which from about 11 to 17 kilograms of soil were employed; in which seldom less than 10, and frequently nearer 25 grams of combined nitrogen were involved; in which, with these quantities, the soils and plants were exposed to free air and rain; and in which, under such conditions, there was, with the same description of plant, sometimes loss and sometimes considerable gain of nitrogen indicated. In the case of Papilionaceæ growing in sand without or with only comparatively small additions of combined nitrogen, but with due microbe infection, inducing root nodule formation, the gains are proportionately so great as to render immaterial the usual sources of erro incident to experiments in the open air, and to leave no doubt whatever whether there had been fixation or not. At present, therefore, it must be considered that the fixation of free nitrogen by the higher chlorophyllous plants themselves still requires confirmation. It may be added that what is known of the nitrogen statistics of the growth in agriculture of other cruciferous plants is adverse to the supposition that they avail themselves of the free nitrogen of the atmosphere.

But to return to the question of the explanation of the undoubted fixation of free nitrogen in the growth of leguminous crops under the influence of suitable microbe infection and of the development of nodules on the roots of the plants.

As in the exact quantitative series of experiments made at Rothamsted in 1888 and since, some of the results of which have been briefly described, the plants were not taken up until they were nearly ripe, it is obvious that the roots and their nodules could not be examined during growth, but only at the conclusion, when, if the gain of nitrogen be connected with their development, it would be supposed that they would be to a great extent exhausted of their nitrogenous contents. Another series was therefore commenced in 1890, and is still in progress, in which the same four annuals, peas, beans, vetches, and yellow lupines, and the same four plants of longer life, white clover, red clover, sainfoin, and lucern, were grown in specially made pits, so arranged that some of the plants of each description could be taken up and their roots and nodules studied at successive periods of growth: The annuals at three periods, namely, first, when active vegetation was well established; secondly, when it was supposed that the point of maximum accumulation had been approximately reached; and thirdly, when nearly ripe; and the plants of longer life at four periods, namely, at the end of the first year, and in the second year, when active vegetation was reestablished, when the point of maximum accumulation had been reached, and lastly, when the seed was nearly ripe. Each of the eight descriptions of plant was grown in sand (with the plant ash),

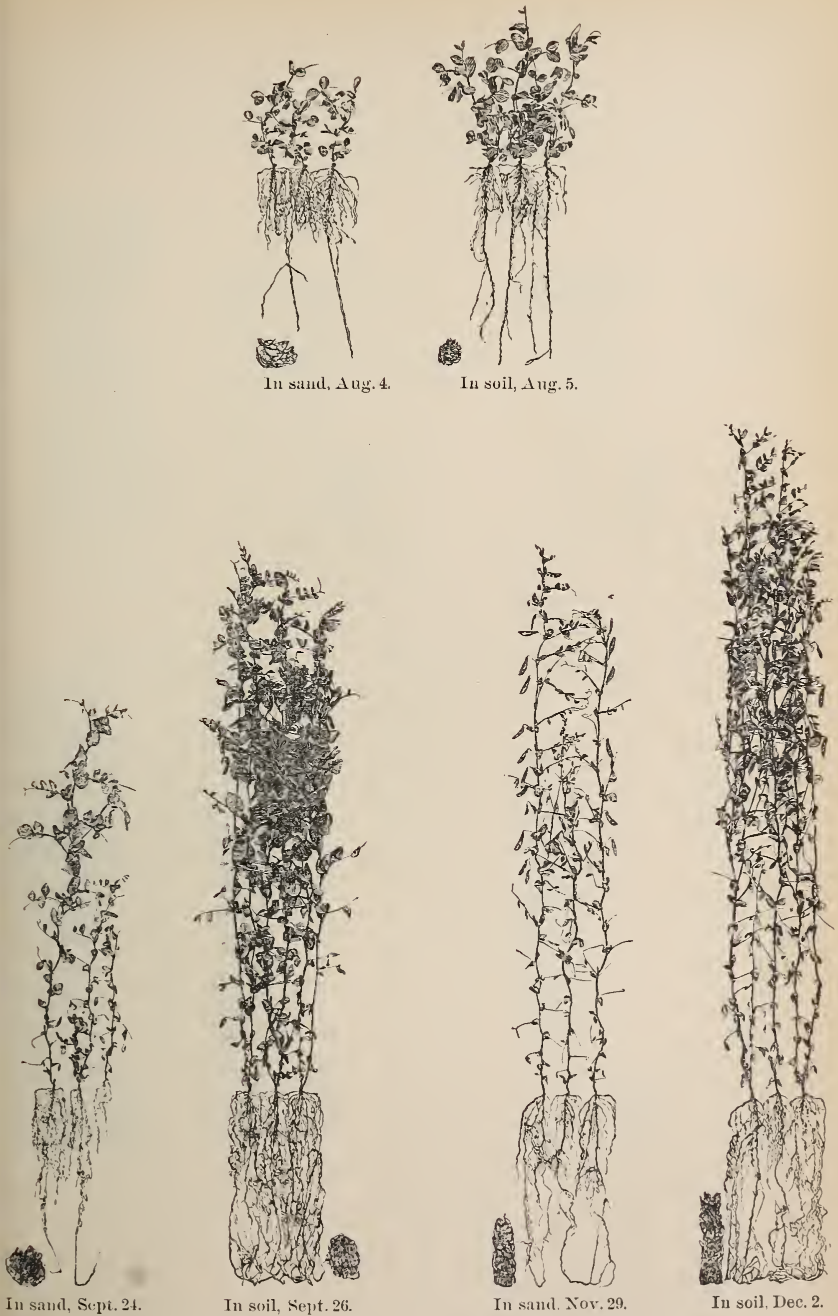

FIG. 4.—Peas grown in experiments on the fixation of free nitrogen, 1890.

watered with the extract from a rich soil; also in a mixture of two parts rich garden soil and one part of sand. The pits, with their plants, were exposed to the open air, but protected from heavy rain.

In the sand the infection was comparatively local and limited, but some of the nodules developed to a great size on the roots of the weak plants so grown. In the rich soil the infection was much more general over the whole area of the roots, the nodules were much more numerous, but generally very much smaller. Eventually the nodules were

In sand, Dec. 10, 1890. In soil, Dec. 13, 1890. In sand, May 15, 1891. In soil, May 15, 1891.

In sand, June 12, 1891. In soil, June 12, 1891. In sand, Sept. 11, 1891. In soil, Sept. 14, 1891.

FIG. 5.—Sainfoin grown in experiments on the fixation of free nitrogen.

picked off the roots, counted, weighed, and the dry substance and the nitrogen in them determined.

Among the annuals the peas, and among the plants of longer life the sainfoin, showed perhaps the most normal growth; and figs. 4 and 5 and the results given in Table 46 (p. 139) afford interesting illustrations.

TABLE 16.—*Experiments at Rothamsted on the fixation of free nitrogen—Plants grown in pits and taken up at successive periods, 1890–91 (1, in sand (with ash), microbe seeded; 2, in a mixture of rich soil and sand).*

	Date of taking up.	Number of plants grown.	Nodules.			
			Approximate number.	Weight, dried at 100° C.	Nitrogen.	
					In dry.	Actual.
PEAS, 1890.						
In sand:				*Grams.*	*Per cent.*	*Grams.*
First period	Aug. 4, 1890	3	(253)	0.229	6.630	0.0152
Second period	Sept. 24, 1890	3	(335)	.516	3.592	.0185
Third period	Nov. 29, 1890	3	(328)	.162	2.104	.0034
In soil:						
First period	Aug. 5, 1890	3	(324)	.743	5.022	.0373
Second period	Sept. 26, 1890	3	(1,253)	1.497	3.167	.0474
Third period	Dec. 2, 1890	3	(1,512)	1.600	2.797	.0447
SAINFOIN, 1890–91.						
In sand:						
First period	Dec. 10, 1890	3	(82)	.153	7.346	.0112
Second period	May 15, 1891	3	(148)	.229	5.792	.0133
Third period	June 12, 1891	3	(360)	1.043	6.151	.0641
Fourth period	Sept. 11, 1891	3	(2,891)	4.403	4.735	.2085
In soil:						
First period	Dec. 13, 1890	3	(226)	.040	6.259	.0025
Second period	May 15, 1891	3	(2,018)	1.492	6.286	.0937
Third period	June 12, 1891	2	(1,125)	.649	6.363	.0412
Fourth period	Sept. 14, 1891	3	(2,412)	3.299	7.066	.2331

It is seen that, stated very briefly, the general result was that at the third period of growth of the peas in sand the amount of dry matter of the nodules was very much diminished, the percentage of nitrogen in the dry matter was very much reduced, and the actual quantity of nitrogen remaining in the total nodules was also very much reduced. In fact, the nitrogen of the nodules was almost exhausted. The peas grown in rich soil, however, maintained much more vegetative activity at the conclusion and showed a very great increase in the number of nodules from the first to the third period; and with this there was also much more dry substance and even a greater actual quantity of nitrogen in the total nodules at the conclusion. Still, as in the peas grown in sand, the percentage of nitrogen in the dry substance of the nodules was very much reduced at the conclusion.

In the case of the plant of longer life, the sainfoin, there was, both in sand and in soil, very great increase in the number of nodules and in the actual amount of dry substance and of nitrogen in them as the growth progressed. The percentage of nitrogen in the dry substance of the nodules also showed, even in the sand, comparatively little reduction, and in the soil even an increase. In fact, separate analyses of nodules of different character or in different conditions showed that whilst some were more or less exhausted and contained a less percentage of nitrogen, others contained a high percentage and were doubtless new and active. Thus the results pointed to the interesting conclusion that in the case of the annual, when the seed is formed and the plant more or less exhausted, both the actual amount of nitrogen in the nodules and its percentage in their dry substance are greatly

reduced, but that with the plant of longer life, although the earlier formed nodules become exhausted, others are constantly produced, thus providing for future growth. The results of this new series of experiments taken together with those of the quantitative series also serve further to show that there is intimate connection between the gain of nitrogen by Leguminosæ and the development of nodules on their roots.

The alternative explanations of the fixation of free nitrogen in the growth of Leguminosæ seem to be: (1) That under the conditions of the symbiosis the plant is enabled to fix the free nitrogen of the atmosphere by its leaves; (2) that the nodule organisms become distributed within the soil, and there fix free nitrogen, the resulting nitrogenous compounds becoming available as a source of nitrogen to the roots of the higher plant; (3) that free nitrogen is fixed in the course of the development of the organisms within the nodules and that the resulting nitrogenous compounds are absorbed and utilized by the host.

Certainly the balance of the evidence at present at command is much in favor of the third mode of explanation. Indeed, there seems nothing in the facts to lead to the conclusion that under the influence of the symbiosis the higher plant itself is enabled to fix the free nitrogen of the air by its leaves. Nor does the evidence point to the conclusion that the nodule organisms become distributed through the soil, and there fix free nitrogen, the compounds of nitrogen so produced being taken up by the higher plant. It seems much more consistent, both with the experimental results and with general views, to suppose that the nodule organisms fix free nitrogen, and that the nitrogenous compounds produced are absorbed and utilized by the plant. In other words, there does not seem to be any evidence that the higher chlorophyllous plant itself fixes free nitrogen, or that the fixation takes place within the soil; but it is much more probable that the lower organisms fix the free nitrogen. If this should eventually be established, we have to recognize a new power of living organisms—that of assimilating an elementary substance. But this would only be an extension of the fact that lower organisms are capable of performing assimilation work which the higher can not accomplish, while it would be a further instance of lower organisms serving the higher.

Lastly, it may be observed that Loew has suggested that the vegetable cell, with its active protoplasm, if in an alkaline condition, may fix free nitrogen with the formation of ammonium nitrate. Without passing any judgment on this point it may be stated that it has frequently been found at Rothamsted that the contents of the nodules have a weak alkaline reaction when in apparently an active condition; that is, while still flesh red and glistening.

It will be seen that the experimental results which have been brought forward constitute only a small proportion of those obtained at Rothamsted, and it is hoped that when the investigations and the study of the results are completed more definite answers will be forthcoming to

some of the admittedly still open questions in connection with this interesting and important subject.

OF WHAT IMPORTANCE TO AGRICULTURE IS THE NEWLY RECOGNIZED SOURCE OF NITROGEN TO LEGUMINOUS CROPS?

The question yet remains, What is the practical importance of the newly recognized source of nitrogen to the Leguminosæ, considered in its bearing on the known facts of agricultural production, and especially on the question of the sources of the nitrogen, not only of leguminous crops themselves, but of crops generally? Unfortunately, as in the matter of the explanation of the action by which the nitrogen is fixed, there is much yet to learn before an adequate answer can be given. Still, it is desirable to report progress.

It has been stated that the characteristic nodules have been found on the roots of various leguminous plants growing among the mixed herbage of grass land, and also on those of others growing on arable land in the ordinary course of agriculture. There can be little doubt that, when such plants are growing in soil and subsoil containing an abundance of combined nitrogen, they will obtain some of their nitrogen from nitrates or other ready-formed compounds of nitrogen. An apparent difficulty in the way of the assumption that much of the greater assimilation of nitrogen by the Leguminosæ than by other plants is due to a supply of nitric acid by the nitrification of the combined nitrogen of the subsoil is that the direct application of nitrates as manure has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as sodium or calcium nitrate, unaccompanied by the other necessary mineral constituents in an available condition; whereas, in the case of nitric acid being formed as a result of action on the organic nitrogen of the subsoil, it is probable that it will be associated with other constituents, liberated, and so rendered available at the same time. But, so far as the plants do obtain nitrogen derived from the fixation of free nitrogen, the question arises, Under what conditions will this supply come the more or less into play?

In the later series of experiments made at Rothamsted, those conducted in pits in the open air, to which brief reference has been made, the general, though not the invariable, result was that there was a much greater number of nodules formed on the roots of the plants growing in rich soil than on those grown in sand. But while as a rule the individual, but much fewer, nodules on the roots grown in sand developed to a much greater size, the much larger number in the soil were very much smaller.

As to the smaller number of nodules formed in sand than in rich soil, the explanation may simply be that, as in the sand the infection was dependent on the additions of rich soil extract only, the diffusion of the

microbes would be only limited, and the infection of the roots, therefore, only local or accidental, while the much greater size of the individual nodules may be due to the want of power in the more weakly plant growing in nitrogen-free soil to resist the free development of the parasite. On the other hand, in the mixture of rich soil and sand the microbes would probably be distributed throughout it and the roots accordingly exposed to infection along their whole range. The much less development of the individual but more numerous nodules in the rich soil may be due to one of two very different causes. It may be that although the more vigorous plants grown in the rich soil could not resist the original infection, they were able to resist the further development of the parasite; or, it may be that with the vigorous growth the nodules were more rapidly exhausted of their contents to feed the host. It will be obvious that, on the former supposition, some of the nitrogen of the restrictedly developed individual nodules may have been obtained from the nitrogenous matters of the plant itself, derived from soil nitrogen; in which case the gain from fixation would be less than would otherwise be indicated by the great number of the nodules produced; and, in favor of this supposition, which implies that in the early stages of the infection the bacteria derive nitrogenous nutriment from the stores of the higher plant itself, and only later from the fixation of free nitrogen, is the fact of the observed "nitrogen hunger stage" so characteristic of plants for some time after infection, when growing in nitrogen-free soil; probably indicating that during that period the limited stores of the plant are being drawn upon. On the second supposition, on the other hand—namely, that the smallness of the nodules was due to their rapid exhaustion by the host, it might be that more of the nitrogen of the nodules would be due to fixation, and that hence a larger proportion of the total nitrogen of the plant would be gain, attributable to that source.

Obviously more evidence is needed before a decisive opinion can be formed as to how far fixation of free nitrogen is an essential coincident of nodule development at all its stages of accumulation, and how far, therefore, the amount of nodule formation may be taken as a fair measure of the fixation.

It is to be supposed that when nodules develop abundantly on the roots of leguminous plants growing in soil rich in readily available combined nitrogen, the nitrogen assimilated will be partly due to soil supplies of combined nitrogen, and partly to fixation. That there is gain when red clover, for example, grows luxuriantly on ordinary arable soil, common experience can leave but little doubt. The evidence of fixation is, however, undoubtedly much the clearer in the case of soils poor in nitrogen. Thus, in the cases of the experiments with peas, vetches, and yellow lupines, growing in nitrogen-free but duly infected sand, there being no other supply of combined nitrogen excepting that in the seed sown, the proportion of the total assimilation due to fixation

was undoubtedly very large. It may safely be concluded, indeed, that when luxuriant leguminous crops are obtained on soils characteristically poor in available combined nitrogen, a large proportion of the total nitrogen assimilated will be due to fixation. It is, on the other hand, by no means so clear that, when such plants are grown in soil rich in available combined nitrogen, an abundant development of nodules is to be taken as indicating that a correspondingly great proportion of the total nitrogen assimilated is due to fixation. There can, however, be little doubt that in the growth in practical agriculture of leguminous crops, such as clover, vetches, peas, beans, sainfoin, lucern, etc., at any rate some, and in some cases a considerable proportion of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, is due to the fixation of free nitrogen, brought into combination by the agency of lower organisms. Evidence is, however, obviously still wanting to enable us to judge decisively under what conditions a greater or less proportion of the total nitrogen of the crop will be derived—on the one hand from nitrogen compounds within the soil, and on the other from fixation.

Incidentally, the question suggests itself, How far the failure of red clover, or of other leguminous crops, may be due to the exhaustion of the organisms necessary for nodule development, and for the coincident fixation of free nitrogen; how far to the exhaustion of combined nitrogen, or of the necessary mineral constituents, in an available condition, within the range of the roots; or, as is sometimes the case, to insect ravages due to the condition of the soil independently of an otherwise failing condition of the plant?

Assuming it then to be established that a greater or less, and sometimes a considerable proportion, of the nitrogen of our leguminous crops will be due to fixation under the conditions supposed, it is obvious that such a fact not only serves to explain the source of the hitherto unaccounted-for amount of the nitrogen of those crops themselves, but that it also affords an explanation of the source of the increased amount of nitrogen which other crops acquire when they are grown either in association or in alternation with Leguminosæ. Lastly, the fact that, at any rate, many leguminous plants, including papilionaceous shrubs and trees, as shown by Nobbe, are susceptible to the symbiosis, and under its influence may gain much nitrogen, serves to explain the source of some, at least, of the large amount of combined nitrogen accumulated through ages in our soils and subsoils, and also the comparatively slow exhaustion of their stores of it by cropping, drainage, and in other ways.

I will, in conclusion, refer to some of the more directly practical aspects of the subject. It may be observed that in Germany, Schultz, of Lupitz, has for some years devoted a considerable area of poor gravelly and sandy soil to the growth of leguminous crops, various clovers,

lupines, serradella (*Ornithopus sativus*), etc., by means of kainit and phosphatic manures, and he has found that the land was thereby very much enriched for future cereal and other crops. He finds, however, that it is necessary to vary the description of leguminous crop grown. In other parts of Germany, too, the system is gradually extending of growing lupines, serradella, or other leguminous crops, especially on poor sandy soils, with a view to their enrichment in nitrogen. And on a large estate in Hungary I found that the results of the recent investigations indicating the fixation of free nitrogen in the course of the development of leguminous crops were being carefully studied with a view to practical application.

In our own country, Mr. Mason, of Eynsham Hall, Oxfordshire, after first making some experiments with various Leguminosæ on small plats, and then a considerable series in specially built tanks or pits, devoted about 200 acres to the practical application of the recently acquired knowledge in regard to nitrogen fixation. Stated in a few words, his idea is to reduce his area under roots, and to grow instead mixed crops of Leguminosæ—beans, various clovers, etc.—liberally manured with basic slag and kainit, and to convert the produce in the first year into silage, and in the second into hay. The land is thus occupied for two years, and the assumption is that in this way highly nitrogenous crops will be obtained with mineral but without any nitrogenous manure, and that the land will be left in high condition, so far as nitrogen is concerned, for the growth of salable crops, such as grain and potatoes, which require nitrogenous manuring. In other words, the plan is, as he puts it, first to grow nitrogen-accumulating crops for home consumption, and afterwards nitrogen-consuming crops for sale. The experiment has been in progress too short a time to judge how far it will be successful in a series of years or of rotations.

There is, of course, nothing new in the fact that after the growth of a leguminous crop, such as red clover, for example, the soil is left in a higher condition for the subsequent growth of a grain crop; and that, in fact, the growth of such a leguminous crop is to a great extent equivalent to the application of a nitrogenous manure for the cereal. Indeed, history tells us that more than two thousand years ago it was recognized by the Romans that the occasional growth of plants of the leguminous order had the effect of increasing the growth of the gramineous crops with which they were alternated; and it was stated that the effect was equivalent to that of applying manure. Thus, Varro says that "certain things are to be sown, not with the hope of any immediate profit being derived from them, but with a view to the following year, because, being plowed in and then left in the ground, they render the soil afterwards more fruitful;" and the plants used for this purpose were lupines, beans, vetches, and other legumes.

Now, however, that the character of the action is more clearly understood, and it is certain that there is actual gain of nitrogen from sources external to the soil itself, it seems desirable that at any rate tentative

trials should be made on different descriptions of soil, with a view of ascertaining whether more advantage can not be taken of this source of nitrogen than our established practices of rotation at present secure.

To sum up, the experimental results which have been brought forward clearly establish that there is great gain of nitrogen under some conditions. It has also been clearly shown that due infection of the soil and of the plant is an essential to success. The evidence at the same time points to the conclusion that the soil may be only infected for the growth of one description or some descriptions of leguminous plants, but not for some other descriptions. The field experiments on such plants at Rothamsted have further shown that land which is, so to speak, quite exhausted so far as the growth of one leguminous crop is concerned, may still grow very luxuriant crops of another description of the same order, but of different habits of growth, and especially of different character and range of roots. This result, though undoubtedly more or less due to other causes also, is, nevertheless, in some cases doubtless dependent on the existence, the distribution, and the condition of the appropriate microbes for the due infection of the different descriptions of plant. In fact, it is pretty certain that success in any system involving a more extended growth of leguminous crops in our rotations will not be attained without having recourse to a considerable variation in the description grown. Other essential conditions of success will generally be the liberal application of potash and phosphatic manures, and sometimes chalking or liming for the leguminous crop. Then the questions would arise, how long the leguminous crop should occupy the land; to what extent it should be consumed on the land, or the manure from its consumption be returned; or, under what conditions the whole or part of it should be plowed in. Lastly, it is probable that more benefit would accrue to the lighter and poorer than to the heavier or richer soils by any such extended growth of leguminous crops.

SECTION IV.

EXPERIMENTS ON THE GROWTH OF WHEAT, FOR FIFTY YEARS IN SUCCESSION ON THE SAME LAND, BROADBALK FIELD, ROTHAMSTED.

INTRODUCTION.

It has already been pointed out, that although wheat and barley are closely allied botanically, and they have in some respects very similar requirements, yet that there are distinctions as well as similarities which have to be borne in mind. Thus, while in our country and climate barley is generally sown in the spring, wheat is almost always sown in the autumn, and thus has four or five months for root development, and for gaining possession of range of soil, before barley is sown. In the United States, on the other hand, wheat is to a great extent both a spring and an autumn-sown crop. At any rate, it is so important a crop in some of the States that results relating to its growth, even under widely different conditions, can hardly fail to be of interest to those connected with American agriculture.

THE FIELD EXPERIMENTS ON WHEAT.

The experiments on the continuous growth of wheat at Rothamsted were commenced in the autumn of 1843, the first experimental crop being harvested in 1844; so that the crop of the present year, 1893, is the fiftieth grown in succession on the same land: (1) Without manure; (2) with farmyard manure; (3) with a great variety of chemical manures.

Table 47 gives the number of bushels of dressed grain per acre, without manure, and with farmyard manure, in each of the fifty years, 1844 to 1893 inclusive; also on some of the artificially-manured plats, mainly selected to illustrate the effects of exhaustion and of manure residue. In most cases in this table, and in all of the subsequent tables, the results obtained on the artificially-manured plats are only given for the last forty-two of the fifty years; as, during the first eight years, various mineral and nitrogenous manures were applied, but not, as a rule, the same from year to year on the same plat, as they were subsequently.

WITHOUT MANURE EVERY YEAR.

After a five-course rotation since manuring (turnips, barley, peas, wheat, oats), the first experimental wheat crop was harvested in 1844. The highest yield of the whole series of years without manure was 23¼ bushels in 1845, and the lowest 4¾ bushels in 1879. Other yields have been 21⅛ bushels in 1854, 20 in 1857, only 5⅝ in 1853, and only 8 to 9 bushels in 1867, 1875, 1876, and 1877.

The upper part of the table (47) shows that the average produce without manure over the first eight years, 1844–1851, was $17\frac{3}{8}$ bushels, which was higher than over either of the subsequent eight-yearly periods, due doubtless to a greater amount of comparatively recent accumulations from the previous treatment. In the bottom division of the table is given the average produce for each of the subsequent eight-yearly periods, and for the forty years, 1852 to 1891, inclusive; also for the whole period of fifty years, 1844–1893. It is seen that, without manure, the average annual produce over these eight-yearly periods was $16\frac{1}{8}$, $13\frac{1}{2}$, $12\frac{1}{4}$, $10\frac{1}{2}$, and $12\frac{3}{4}$ bushels; over the forty years (1852–1891) 13, and over the fifty years (1844–1893) $13\frac{1}{2}$ bushels.

There can be no doubt that the produce of the unmanured plat has gradually declined; and, independently of the evidence of diminishing produce, analyses of the soil at different periods show that there has been a gradual diminution in the amount of nitrogen in it. But owing to the great fluctuations in the amount of produce from year to year dependent on season, it is by no means easy to estimate the decline due to exhaustion of the soil, as distinguished from variations due to the seasons.

In the first place, it is difficult to say what figure should be adopted as the standard produce of the plat by which to compare the yields from year to year. The whole field was manured with farmyard dung in 1839, and then grew turnips (fed on the land), barley, peas, wheat, and oats, before the commencement of the experiments in 1843–44. The plat then grew eight crops of wheat without manure, to 1850–51, before the commencement of the period of forty years to which the averages which have been quoted refer. Although at the conclusion of the five-course rotation since manuring, above described, the land would doubtless be, in an agricultural sense, so far exhausted as to require remanuring, there can be no doubt that there would nevertheless be some accumulation due to comparatively recent manuring and cropping. It would be supposed, however, that the growth of wheat for eight years in succession without manure would remove most, if not all, accumulation which could be attributed to comparatively recent treatment. Indeed, there can be little doubt that the land would suffer more or less exhaustion during those eight years; but, as serving to counteract the tendency to decline in yield from exhaustion during that period, it happened that, taken together, those eight seasons were of more than average productiveness.

As to the rate of decline due to exhaustion, as distinguished from fluctuation due to season, the general result may be stated as follows:

Assuming, for reasons which were fully considered, the standard produce of the unmanured plat to have been 16 bushels per acre independently of material exhaustion, there was an average decline from year to year of little more than one-sixth of a bushel over the forty

years, 1852–1891. It remains to be seen what will be the result in the future; and whether a point has already been, or will in time be reached, at which the produce will remain constant, excepting so far as it is influenced by the fluctuations of the seasons.

It is estimated that over the period of thirty years, 1851–52 to 1880–81, the unmanured plat yielded an average of 18.6 pounds of nitrogen per acre per annum in the crop, and lost a minimum of 10.3 pounds in drainage, in all 28.9 pounds; while on the mixed mineral manure plat (5) it is estimated that the crop removed an average of 20.3 pounds of nitrogen, and that at least 12 pounds were lost by drainage, or in total 32.3 pounds. Further, it is estimated that the soils lost to the depth of 27 inches about two-thirds of these amounts; leaving, say, 10 pounds, more or less, to be otherwise accounted for. Of this, the rain, etc., would supply 5 pounds, or perhaps, rather more, and the seed about 2 pounds, so that there is but little to be provided from all other sources. Further, as at the commencement the soil was, agriculturally speaking, exhausted, the nitrogen supplied by it would be largely due to old accumulations.

Lastly, in regard to the produce of wheat grown so many years in succession without manure, it may be observed that the average yield over forty years, 1852–1891, was 13 bushels per acre per annum, which is more than the average of the whole of the United States, including their rich prairie lands; indeed it is more than the average yield per acre of the wheat lands of the whole world. That the result is not due to richness of soil will be obvious from the fact that the percentage of nitrogen in the dry sifted soil, exclusive of stones, from samples taken in 1893 of every 9 inches of depth down to 12 times 9, or to a total depth of 9 feet, was, for the respective depths from the first to the twelfth, as follows: 0.1110, 0.0720, 0.0609, 0.0482, 0.0445, 0.0436, 0.0335, 0.0284, 0.0264, 0.0214, 0.0219, and 0.0251.[1] Thus, the percentage of nitrogen in the surface soil is considerably lower than in the average of wheat lands in Great Britain; it is considerably less than half as high as in the case of average permanent meadow lands; and it is only about one-third as high as published analyses show in some Illinois prairie soils. The subsoils are also very poor in nitrogen. It is further to be observed that a full mineral manure annually applied gave less than three-fourths bushel per acre per annum more than the unmanured plat. Hence, it may be concluded that it was not owing to any deficiency of mineral supply, but of nitrogen, that the limitation of the produce was due. On the other hand, that with a soil so poor in nitrogen, the yield was nevertheless higher than the average of the United States, or of the world at large, is to be explained by the fact that great care is taken to keep down weeds, which would otherwise appropriate a large share of such fertility as the soil possessed.

[1] These samples were taken from only one place for the Chicago Exposition.

FARMYARD MANURE EVERY YEAR.

In the application of farmyard manure every constituent is supplied in excess. The highest yields of the series of years were $48\frac{1}{2}$ bushels in 1891, 44 in 1863, 43 in 1890, $41\frac{3}{4}$ in 1868, $41\frac{1}{4}$ in 1857, $41\frac{1}{8}$ in 1854, $40\frac{1}{2}$ in 1889, $40\frac{1}{8}$ in 1885, and 40 bushels in 1864. The lowest yields were 16 bushels in 1879, $19\frac{1}{8}$ in 1853, $20\frac{1}{2}$ in 1844, $23\frac{7}{8}$ in 1876, and $24\frac{1}{8}$ in 1877.

The average produce per acre per annum over the first eight years was 28 bushels; and the average over each of the five subsequent eight-yearly periods was $34\frac{3}{8}$, $35\frac{3}{4}$, $35\frac{3}{8}$, $28\frac{5}{8}$, and $39\frac{1}{4}$ bushels. Excluding the first eight years, the average produce over the forty years, 1852–1891, was $34\frac{7}{8}$ bushels; and the average for the whole period of fifty years, 1844–1893, was $33\frac{1}{2}$ bushels per acre per annum.

On the farmyard manure plat the first depth of 9 inches shows a great accumulation. It is about twice as rich in nitrogen as any other plat in the field; yet this richness is not proof against bad seasons, nor are the highest amounts of produce in the field obtained on this plat.

It has been seen that the unmanured plat has declined in yield and fertility; but there can be no doubt that the farmyard manure plat has, on the other hand, increased in fertility. Analyses of the surface soil at different periods have shown that it has become about twice as rich in nitrogen as that of the unmanured plat. It has, indeed, been shown that a large amount of the constituents of farmyard manure accumulates within the soil, and that they are very slowly taken up by crops. In fact, notwithstanding this great accumulation within the soil, the wheat crops on the dunged plat seldom, if ever, show over luxuriance, and in unfavorable seasons the produce has been comparatively small, largely owing to the encouragement of weeds, and especially of grass, which in wet seasons it has been impossible effectually to eradicate, and what has been done has not been accomplished without injury to the crop.

Let us now endeavor to estimate the average annual increase of produce on the farmyard manure plat due to accumulation independently of fluctuations due to season, as we did the annual decline in yield on the unmanure plat due to gradual exhaustion. As in the case of the unmanured plat, so in that of the farmyard manure plat, we have founded an estimate of its standard produce, irrespectively of material accumulation, on the yield of the first eight years, deducting, however, the produce of the first year of all, 1844, as although the yield of the crop of the country at large in that year was high, that of the farmyard manure plat was only 20 bushels. Taking the average of the remaining seven years of the eight we get 29.3 bushels, while three of the seven yielded more than 30 and two others 29 bushels or more. Adopting, then, 29.3 bushels as the standard yield, irrespective of material accumulation, the result would be an average annual increase

due to accumulation of 5⅛ bushels over the forty years, while the average increase from year to year, if uniform throughout the period, would be a little over one-quarter bushel over the forty years.

In conclusion, it is seen that the average produce of the forty years by farmyard manure was nearly 35 bushels, which is about seven bushels more than the average of the United Kingdom under ordinary cultivation, and it is not far short of three times as much as the average of the United States, or of the whole world.

VARIOUS ARTIFICIAL MANURES.

The next question is, which constituents of farmyard manure are the most effective for wheat in this agriculturally exhausted rather heavy soil, with a raw clay subsoil. The first illustrations on this point will be drawn from Table 48.

TABLE 48.—*Wheat grown for more than fifty years in succession on the same land, commencing 1843–44—Results showing the effects of different manures for forty-three years, 1852–1894, inclusive (quantities per acre)—Produce (dressed grain in bushels).*

	Superphosphate, and sulphates potash, soda, and magnesia—					Sodium nitrate alone=86 pounds[2] nitrogen.
	Alone.	And ammonium salts=43 pounds nitrogen.	And ammonium salts=86 pounds nitrogen.	And ammonium salts=129 pounds nitrogen.	And sodium nitrate=86 pounds[1] nitrogen.	
Plats	5.	6.	7.	8.	9*a*.	9*b*.
Harvests:	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1852	16⅞	20⅞	26¾	27½	25½	24½
1853	19½	18⅛	23⅝	23½	11¼	10½
1854	24¼	34⅛	45½	48⅝	38¾	38⅞
1855	18¼	28	33	31½	29⅝	25⅜
1856	19½	27¾	36⅞	39⅛	32⅜	26
1857	23¾	35⅜	44⅞	48⅜	43¾	36¼
1858	18⅞	28⅞	39⅛	41⅞	37⅝	23½
1859	20⅝	29⅞	34⅝	34½	30	24⅝
1860	15⅞	22	27¾	31¼	32⅝	19⅝
1861	15½	27⅝	35	35⅛	33¾	13¾
1862	17¾	28¼	35⅞	39½	43½	25⅞
1863	19⅝	39⅝	53⅝	55¾	55⅝	41½
1864	16⅞	31⅛	45¾	49⅞	51⅛	33½
1865	14¼	25	40¼	43⅝	44⅛	29⅝
1866	13¼	20½	29⅞	32⅛	32½	30¾
1867	9¼	15¾	22⅛	30½	29⅛	22⅛
1868	17⅝	28⅜	39⅞	46½	47⅞	27¼
1869	15¾	21⅝	28⅜	34¾	39	24⅛
1870	18⅞	30½	40½	45¼	45½	26½
1871	11⅞	17	22¼	27¾	34½	17⅝
1872	12¾	20½	29¾	35⅝	40¾	23⅜
1873	12¾	15⅞	22	27½	35⅞	21⅞
1874	13	25⅞	39½	40½	38¼	21½
1875	9¼	16⅜	25⅞	30	30½	16½
1876	10½	15¾	23½	29⅝	33⅜	13
1877	11⅝	14⅝	19⅞	24¾	40⅛	27¾
1878	14¾	22¾	31¼	38⅛	37¼	23⅜
1879	5⅝	10½	16¼	20⅝	22	4⅝
1880	17¾	27	34½	35⅜	34⅛	10½
1881	12¾	21¾	26⅝	30¾	35½	22¾
1882	12½	23⅛	35¾	37	31⅞	24⅜
1883	15¾	27⅝	36⅛	41⅞	43⅜	19⅛

[1] 9*a*. Nitrate of soda, equal 74 pounds nitrogen in 1852; equal 43 pounds nitrogen in 1853 and 1854; equal 86 pounds nitrogen in 1854 and each year to 1884 inclusive; and equal 43 pounds nitrogen in 1885 and each year since. No mineral manures applied in 1852, 1853, or 1854.

[2] 9*b*. Nitrate of soda, equal 74 pounds nitrogen in 1852; equal 86 pounds nitrogen in 1853, and each year to 1884 inclusive; and equal 43 pounds nitrogen in 1885 and each year to 1893 inclusive. In 1894 manured exactly as Plat 9*a*.

TABLE 48.—*Wheat grown for more than fifty years in succession on the same land, commencing 1843–44, etc.*—Continued.

	Superphosphate, and sulphates potash, soda, and magnesia—					Sodium nitrate alone = 86 pounds[2] nitrogen.
	Alone.	And ammonium salts = 43 pounds nitrogen.	And ammonium salts = 86 pounds nitrogen.	And ammonium salts = 129 pounds nitrogen.	And sodium nitrate = 86 pounds[1] nitrogen.	
Plats	5.	6.	7.	8.	9*a*.	9*b*.
Harvests—Continued.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1884	15½	26⅛	38⅜	43½	40½	27¼
1885	15¼	22	31½	36¾	31⅛	23¼
1886	11¼	22⅛	35¼	42⅜	32½	15⅞
1887	14½	23¼	29½	34½	30¾	23½
1888	12	23½	35⅞	35¼	28¼	16
1889	15⅛	23	30¾	35½	26¼	12¾
1890	14½	28⅝	36	37⅝	31¾	18¼
1891	11¼	26⅛	40⅝	40	35	22⅜
1892	10⅜	22	32	38⅛	25¼	10¾
1893	14¼	19⅜	20¼	21¾	17⅞	10
1894	22⅜	38	48⅜	49	43⅜	41½
AVERAGES.						
8 years, 1852–59	19	27⅞	35½	36⅞	31⅛	26¼
8 years, 1860–67	15¼	26¼	36¼	39¾	40¼	27⅛
8 years, 1868–75	14	22	31	36	39	22⅜
8 years, 1876–83	12⅝	20⅜	28	32¼	34¾	18¼
8 years, 1884–91	13¾	24⅜	34¾	38¼	32	20
20 years, 1852–71	17	26½	35¼	38¼	36⅞	26
20 years, 1872–91	12⅞	21¾	31	34¾	34	19⅜
40 years, 1852–91	15	24⅛	33⅛	36½	35⅜	22¾
Excess of average crop over plat 5, in bushels	....	9⅛	18⅛	21½	20⅜	7¾

[1] 9*a*. Nitrate of soda, equal 74 pounds nitrogen in 1852; equal 43 pounds nitrogen in 1853 and 1854; equal 86 pounds nitrogen in 1854 and each year to 1884 inclusive; and equal 43 pounds nitrogen in 1885 and each year since. No mineral manures applied in 1852, 1853, or 1854.

[2] 9*b*. Nitrate of soda, equal 74 pounds nitrogen in 1852; equal 86 pounds nitrogen in 1853, and each year to 1884 inclusive; and equal 43 pounds nitrogen in 1885 and each year to 1893 inclusive. In 1894 manured exactly as Plat 9*a*.

The average of the forty years by mineral manure alone shows an increase of only 2 bushels over that of the unmanured plat, though during the preceding eight years (1844–1851) it had received mineral and nitrogenous manures whilst the unmanured plat had, during the same period, grown eight unmanured wheat crops. The addition to the mineral manure of the first 43 pounds of nitrogen (plat 6) gives an average annual increase of 9⅛ bushels; the second, 43 pounds (plat 7), an increase of 9, and the third, 43 pounds (plat 8), only 3⅜ bushels increase. This result affords an illustration of the inapplicability of conclusions from manure experiments when the condition of the land is too high already or when an excess of manure is applied. A given quantity of nitrogen in the form of nitrate yielded more produce than an equal quantity in the form of ammonia. The nitrate being always applied in the spring was not subject to winter drainage. It is, however, very soluble and becomes rapidly distributed and available, but it is, at the same time, very subject to drainage after sowing if heavy rains follow. Prior to 1878 the ammonium salts were applied in the autumn and a great loss of nitrogen by winter drainage, chiefly as nitrates, was proved. To the loss of nitrogen by drainage reference will be made further on.

Thus, minerals not being deficient, the increase was in proportion to the available nitrogen, when it was not applied in excess.

It will be of interest here to refer to the influence of nitrogenous manures in increasing the production of the nonnitrogenous constituents of our crops, as illustrated in Table 34 (p. 93). It shows the estimated amounts of carbon per acre per annum in various crops grown by mineral manure without nitrogen, and by the same mineral manure and nitrogenous manure in addition. It also shows the gain of carbon, that is, the increased amount of it assimilated per acre, and the gain of carbohydrates, that is, the increased production of them per acre, under the influence of the nitrogenous manures; and lastly, the estimated gain of carbohydrates for 1 of nitrogen supplied in manure.

The figures show that, independently of the underground growth, there was an increased assimilation of carbon per acre, in wheat, of 602 pounds by the application of 43 pounds nitrogen as ammonium salts, of 1,234 pounds by 86 pounds applied as ammonium salts, and of 1,512 pounds by 86 pounds applied as sodium nitrate. Or, reckoning the increased production of the nonnitrogenous bodies—the carbohydrates—by the use of nitrogenous manures, it was estimated that there was an increase of 1,240 pounds of carbohydrates per acre by the application of 43 pounds nitrogen as ammonium salts, of 2,550 pounds by 86 pounds applied as ammonium salts, and of 3,140 pounds by 86 pounds as sodium nitrate. To put it in another way, for 1 pound of nitrogen applied as manure there was an increased production of carbohydrates, in the grain and straw of wheat, of 28.8 pounds when 43 pounds of nitrogen were applied as ammonium salts; of 29.7 pounds when 86 pounds were applied as ammonium salts, and of 36.5 pounds when 86 pounds were applied as sodium nitrate.

It is seen that in the case of the wheat there was much more effect from a given amount of nitrogen supplied as nitrate, which was always applied in the spring, than from an equal quantity as ammonium salts, which was applied in the autumn, when the nitrogen would be subject to winter drainage. Reference to the table will also show that there was more effect from a given amount of ammonium salts applied to barley than to wheat; the application having been made for the barley in the spring, and for the wheat in the autumn.

It should be observed that there was such greatly increased assimilation of carbon in the wheat and in the barley, as the figures show, for more than twenty years, without the addition of any carbon to the soil. It is, indeed, certain that, in the existing condition of our old arable soils, the increased growth of our staple starch-yielding grains is greatly dependent on an available supply of nitrogen within the soil. It is equally certain that the increased production of sugar in the gramineous sugar cane in the Tropics is likewise greatly dependent on the supply of nitrogen within the soil.

In connection with the results showing the increased assimilation of carbon and increased production of carbohydrates under the influence

of nitrogenous manures, it will further be of interest to call attention to the connection between nitrogen accumulation, chlorophyll formation, and carbon assimilation.

TABLE 49.—*Relation of carbon assimilation to nitrogen accumulation and to chlorophyll formed.*

	Nitrogen in dry matter.[1]	Relative amount of chlorophyll.	Carbon per acre per annum.	
			Actual.	Difference.
Hay:	*Per cent.*		*Pounds.*	*Pounds.*
Gramineæ	1.190	0.77		
Leguminosæ	2.478	2.40		
Wheat:				
Plat 10*a*	(1.227)	2	1,398	—824
Plat 7	(0.566)	1	2,222	
Barley:				
Plat 1*a*	(1.474)	3.20	1,403	—685
Plat 4*a*	(0.792)	1.46	2,088	

[1] The figures given in parentheses are on the only partially dried substance.

It should be observed that the amounts of chlorophyll recorded are, as stated, relative, and not actual; and the figures show the relative amounts for the individual members of each pair of experiments, and not the comparative amounts as between one set of experiments and another. It should be further stated that the chlorophyll determinations were kindly made by Dr. W. J. Russell, F. R. S., of London, in specimens collected at Rothamsted, while the wheat and barley were still green and actively growing.

It will be seen, in the first place, that the separated leguminous herbage of hay contained a much higher percentage of nitrogen in its dry matter than the separated gramineous herbage; and that, with the much higher percentage of nitrogen in the leguminous herbage, there was also a much higher proportion of chlorophyll.

Next, it is to be observed that the wheat plant on plat 10*a*, manured with ammonium salts alone, shows a much higher percentage of nitrogen than that of plat 7, with the same amount of ammonium salts, but with mineral manure in addition. The high proportion of chlorophyll again goes with the high nitrogen percentage; but the last column of the table shows that, on plat 10*a*, with ammonium salts without mineral manure, with the high percentage of nitrogen, and the high proportion of chlorophyll in the green produce, there was eventually a very much less assimilation of carbon. The result is exactly similar in the case of the barley; plat 1*a* being manured with ammonium salts alone, and plat 4*a* with the same ammonium salts and mineral manure in addition.

It is evident that the chlorophyll formation has a close connection with the amount of nitrogen assimilated; but that the carbon assimilation is not in proportion to the chlorophyll formed if there is not a sufficiency of the necessary mineral constituents available. No doubt there had been as much or more of both nitrogen assimilated,

and chlorophyll formed, over a given area, where the mineral as well as the nitrogenous manure had been applied; the lower proportion of both in the dry matter being due to the greater assimilation of carbon, and consequent greater formation of nonnitrogenous substance.

The next point to consider is, What is the effect of the unrecovered amount of nitrogen on succeeding crops? This is illustrated by the results in the colored columns of Table 47 (p. 146). In the table mineral manure alone is indicated by blue, nitrogenous manure alone by yellow, and a mixture of the two by green. Plat 5 has been manured continuously for forty-two years with mineral manure alone, while plats 7 and 18 each received, alternately, mineral manure or a quantity of ammonium salts containing 86 pounds of nitrogen. Thus we are able, for every year to compare a plat manured with minerals succeeding a previous application of ammonium salts with a plat receiving mineral manure alone every year. It is seen that in every case the application of nitrogenous manure gave a greatly increased yield, frequently doubling that of the plat with mineral manure alone Again, in every case the yield of the succeeding year, when the mineral manure followed the previous application of ammonium salts, was reduced, approximately, to that of the plat continuously treated with minerals alone. A glance down the columns of plats 17 and 18, each colored alternately blue and yellow, and a comparison of them with the blue column of plat 5, will bring the results strikingly to view. A comparison of the averages of the periods of eight and of forty years of this treatment clearly shows the essential identity of the results of the continuous and the alternate treatment with mineral manures. The averages for the forty years show an increase in the yield of the mineral manure after ammonia over the yield of plat 5 with mineral manure alone every year of only one-fourth of a bushel per acre per annum in a crop of between 15 and 16 bushels. The noneffect, or the absence of residual available nitrogen applied in the form of ammonium salts, is evident. In other words, nitrogen applied as ammonium salts in any one year was practically exhausted that year, in the crop or otherwise, leaving practically none for subsequent action. Lastly, in regard to plats 17 and 18, it is seen that the average produce over forty years of the ammonium salts succeeding the mineral manure is 30½ bushels, or exactly twice as much as that of the mineral manure succeeding the ammonium salt.

Again, plat 16 received annually, for thirteen years, 1852–1864, inclusive, mixed mineral manure and ammonium salts containing a double quantity (172 pounds) of nitrogen; then for nineteen years, 1865–1883, it was left unmanured, and then for the crop of 1884 and each year since, it has received mixed mineral manure and sodium nitrate containing 86 pounds of nitrogen. During the thirteen years of heavy manuring there was a large yield, in two cases exceeding 50 bushels, with an average for the thirteen years of 39½ bushels.

The first three of the succeeding years, during which no manure was applied, the average yield was only $21\frac{5}{8}$ bushels, a decrease of nearly one-half, followed in the succeeding two periods of eight years each by average yields of $16\frac{5}{8}$ and $11\frac{3}{4}$ bushels, against, for the corresponding periods on plat 3, continuously unmanured, $12\frac{1}{4}$ and $10\frac{1}{2}$ bushels. Or, taking the average of the nineteen years of yield without manure on plat 16, we have $14\frac{5}{8}$ bushels, against, over the same years, $13\frac{1}{8}$ bushels on plat 5, with mineral manures only since 1852, and $11\frac{5}{8}$ bushels on plat 3, unmanured since 1839. It is fair to presume, moreover, that some of the greater yields of plat 16 over that of plat 3, from 1865–1883, were due to the residue of the mixed mineral and excessive nitrogenous manure, but perhaps mainly, as will be seen further on, to increased crop residue.

Since the recommencement of the manuring to plat 16 for the crop of 1884, however, the plat has given some heavy yields, notably in 1886 and 1891, and the average for the eight years, 1884–1891, was $37\frac{1}{2}$ bushels, or only $1\frac{3}{4}$ bushels less than on plat 2, which has received 14 tons of farmyard manure per acre each year for the last fifty years.

If, as the above results have demonstrated, there is practically little or no available residue from previous application of ammonium salts, the question arises, What becomes of the nitrogen of the manure not taken up by the immediate crop? This point is illustrated by the results given in Table 50 (p. 156). The plats there tabulated all received the same amount of nitrogen in manure, but with different mineral manures, and they are given in the order of their average annual increased yield of nitrogen in the crops over plat 5, with mineral manure alone. The first column shows the estimated average annual increased yield of nitrogen per acre in the crops; the second the estimated annual loss of nitrogen as nitric acid by drainage; the third the estimated annual excess of nitrogen in the surface soil over that on plat 5, with the mineral manure alone, and the last column shows the relation which the excess in the soil bears to 100 increased yield of nitrogen in the crops.

The plats were manured as follows:

Plat 10. Ammonium salts = 86 pounds nitrogen.
Plat 11. Ammonium salts = 86 pounds nitrogen, and superphosphate.
Plat 12. Ammonium salts = 86 pounds nitrogen, superphosphate, and soda.
Plat 13. Ammonium salts = 86 pounds nitrogen, superphosphate, and potash.
Plat 14. Ammonium salts = 86 pounds nitrogen, superphosphate, and magnesia.
Plat 7. Ammonium salts = 86 pounds nitrogen, superphosphate, soda, potash, and magnesia.
Plat 9. Nitrate of soda = 86 pounds nitrogen, superphosphate, soda, potash, and magnesia.

TABLE 50.—*Experiments on wheat, Broadbalk field, Rothamsted—Estimated nitrogen per acre per annum, thirty years, 1851–1852 to 1880–1881.*

Plats.	In crops over plat 5.	Lost by drainage over plat 5.	In surface soil 9 inches deep over plat 5.	Excess in surface soil to 100 increase in crop.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
10	12.4	31.2	4.8	38.7
11	17.7	28.5	11.6	65.5
12	22.2	24.5	14.6	65.8
13	23.4	25.6	17.8	76.1
14	24.1	27.5	15.5	64.3
7	25.9	19	19.3	74.5
9	26.5	23.7	18.5	71.2

It is seen that the increased yield of nitrogen in the crops varied exceedingly with the same amount supplied in manure, according to the supply of mineral constituents. Plat 10, with the ammonium salts alone, gives the smallest increased yield of nitrogen in the crop; and plats 7 and 9, with the most complete mineral manure, each gives more than twice as much; the other plats giving intermediate amounts.

The order of the estimated loss of nitrogen by drainage is almost the converse of that of the increased yield in the crops. Plat 10, which gives the least increased yield in the crop, shows the greatest loss by drainage; and plats 7 and 9, which yield the greatest increase in the crops, show the least loss by drainage.

The excess in the soils (over plat 5), is obviously much more in the order of the increased yield in the crops. Plat 10, with the least in the increase of crop, and the most in the drainage, shows the least excess in the soil; whilst plats 7 and 9, with the greatest increased yield in the crop, and the least loss by drainage, show the greatest excess in the soil. It is clear, therefore, that whilst the excess in the soil has no direct relation to the amount supplied in the manure, it has a very obvious relation to the increased yield in the crop; in other words, to the amount of growth. The last column of the table brings this out more clearly. Excepting in the case of plat 10, with the ammonium salts alone, there is a general uniformity in the proportion of the excess in the soil over plat 5 to the increased yield in the crop over plat 5; and the variations, such as they are, have an obvious connection with the conditions of growth. Thus, plats 11, 12, and 14, all with a deficient supply of potash, show approximately equal proportions retained in the soil for 100 of increase in the crop. Plats 13, 7, and 9, again, all with liberal supplies of potash, show higher but approximately equal proportions retained in the surface soil for 100 of increased yield in the crop.

From the various results which have been adduced it is obvious that the relative excess of nitrogen in the soils of the different plats is little, if at all, due to the direct retention of the nitrogen of the manure; and

that it is almost exclusively dependent on the difference in the amounts of the crop residues (of the stubble and roots, and perhaps of weeds), of which there will be the more the greater the amount of crop grown.

It may be here observed that the detailed estimates, of which the results given in Table 50 are a summary, do not account for the whole of the nitrogen applied to the experimental plats; and it is believed that most, if not the whole, of the unaccounted-for amounts are due to loss by drainage beyond that estimated from the pipe drainage. However, in the use of ammonium salts or nitrate of soda in smaller quantities per acre than those used in the experiments and in the course of a rotation of various crops, with varying character and range of roots, as in ordinary agriculture, there will be less loss of nitrogen by drainage than that indicated in these experiments. In the Rothamsted soil and subsoil, with chalk below affording good natural drainage, or in soils generally with good drainage, natural or artificial, it is not probable that there is any material loss by evolution as free nitrogen. Where, however, nitrogen is applied in large quantities, as farmyard or other organic manure, there may be considerable loss by evolution as free nitrogen.

The next point to consider is the differences in the amount of crop with equal nitrogen, but different mineral supply. This is illustrated by the results in Table 51 (p. 158), which shows the produce by mineral manures alone, by ammonium salts alone, and by ammonium salts with different mineral manures.

TABLE 51.—*Wheat grown for fifty-one years in succession on the same land—Results showing the effects of mineral manures alone and when used in addition to ammonium salts (quantities per acre)—Produce (dressed grain in bushels.)*

		400 pounds ammonium salts=86 pounds nitrogen per acre per annum—						
	Mixed mineral manure alone.	Alone, 1852 and since; previously mineral manure, 1844; ammonium salts, 1845–51.	Alone, 1852 and since; previously mineral manure, 1844, 1848, and 1850; ammonium salts, 1845, 1847, 1848, 1849, and 1851.	And superphosphate.	And superphosphate and sulphate of soda.	And superphosphate and sulphate of potash.	And superphosphate and sulphate of magnesia.	And superphosphate and sulphates of potash, soda, and magnesia.
Plat	5.	10*a*.	10*b*.	11.	12.	13.	14.	7.
Harvests:	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
8 years, 1844–51.	29	26	24⅜	28½	28⅛	27⅝	27¼	29¼
1852	16⅞	21⅞	22⅛	23¼	24⅜	24	24¾	26¾
1853	10⅛	10	15½	18⅛	22⅞	23	22⅜	23⅝
1854	24¼	34⅜	39¼	43⅞	45⅝	44½	44¾	45½
1855	18¼	20	28⅛	21¾	31¾	30¾	31⅝	33
1856	19½	24¼	27¾	31¼	33⅜	31⅝	34⅝	36⅞
1857	23¾	29⅛	34½	39⅛	43¾	43⅛	43⅜	44⅞
1858	18⅞	22⅞	27¾	32	37⅝	37¼	38⅛	39⅛
1859	20⅝	19	25½	27⅜	34¾	34½	34½	34⅝
1860	15⅞	15⅛	18⅝	22⅜	27⅜	26⅝	27¼	27¾
1861	15½	12⅞	16	24⅜	32⅞	34⅛	33½	35
1862	17¾	23⅛	24⅞	26⅞	33¾	32⅜	31¼	35⅞
1863	19⅝	39⅛	43⅝	45¾	54	53¼	54	5[illegible]⅝
1864	16⅞	32⅛	36¼	36½	44⅝	43¼	41½	45¾
1865	14¼	25¼	30½	27⅜	34⅝	37⅛	36⅝	40¼
1866	13¼	26¼	28½	28	28¼	24¾	28	29⅞
1867	9¼	18⅛	19⅜	22⅛	24½	23⅞	22¾	22⅛
1868	17⅝	24¾	27¾	33½	39⅞	39¼	41¾	39⅞
1869	15¾	20¼	19⅛	22¼	27¼	27¼	27¾	28⅜
1870	18⅞	21¾	23¼	25¼	35¼	37	35¾	40½
1871	11⅞	10⅛	10	11	21⅛	30⅛	24¼	22¼
1872	12¾	18	18¾	27¼	29¼	29⅞	30⅜	29¾
1873	12¾	19⅝	20⅝	19¼	22⅞	23½	24⅛	22
1874	13	25¼	27¼	32⅞	39½	37⅛	36⅝	39½
1875	9¼	12¾	14⅝	18	25¼	27⅛	26¼	25⅞
1876	10½	12⅛	14½	14⅜	19⅛	25⅛	22⅛	23½
1877	11⅝	17¼	18¼	17⅞	17¾	18¼	18½	19⅞
1878	14¾	27⅜	29⅞	29⅝	29¼	29½	32⅛	31¼
1879	5⅝	4	4⅝	11⅛	14	16	16¼	16¼
1880	17¾	10⅝	13½	25¾	29⅜	33	31	34½
1881	12¾	18¼	19¾	21½	23¾	28¼	27⅜	26⅝
1882	12½	23¾	26⅛	30⅜	34⅝	32⅛	34¾	35¾
1883	15¾	17½	18⅜	26⅜	30¾	34⅛	33⅜	36⅛
1884	15½	25	27	32⅛	35¾	33	36¼	38⅜
1885	15¼	24¼	24¾	22½	27⅜	27¼	26⅞	31½
1886	11¼	13½	12½	17¼	26½	37⅜	31	35¼
1887	14½	20¾	23	22	30⅛	26⅜	28¾	29½
1888	12	13¼	10½	11⅜	23¾	33⅜	26½	35⅞
1889	15⅛	11¾	12¾	16¼	24¼	26	24¾	30¾
1890	14½	18¼	20½	25⅝	32⅛	37¼	33⅜	36
1891	11¼	20⅞	22⅞	24⅛	35¾	38	36½	40⅝
1892	10⅜	11	12	15¾	24⅛	28⅞	24⅛	32
1893	14¼	8	8¾	7¾	11½	16½	12⅞	20¼
1894	22⅜	28⅞	31⅜	39	47¼	47¾	44¼	48⅜
AVERAGES.								
8 years, 1852–59	19	22¾	27½	29⅝	34¼	33⅝	34¼	35½
8 years, 1860–67	15¼	24	27¼	29⅛	35	34⅜	34⅜	36¼
8 years, 1868–75	14	19	20⅛	23⅝	30	31⅜	30⅞	31
8 years, 1876–83	12⅝	16⅜	18⅛	22⅛	24⅞	27	27	28
8 years, 1884–91	13¾	18½	19¼	21⅜	29½	32¼	30½	34¾
20 years, 1852–71	17	22½	25⅞	28	33⅞	33⅞	33⅞	35¼
20 years, 1872–91	12⅞	17¾	19	22¼	27½	29⅝	28⅞	31
40 years, 1852–91	15	20⅛	22½	25⅛	30¾	31¾	31⅜	33⅛

Over the forty years, 1852–1891, inclusive, each of the eight differently manured plats received, respectively, the same manure each year. Leaving the details for careful examination and study, it will be well to call special attention to the average yields over the first twenty, the second twenty, and the forty years.

Plat 5, which received mixed mineral manure alone each year, gave, over the first twenty years, an average annual yield of 17 bushels per acre; over the second twenty, 12⅞ bushels, and ov r the whole period of forty years, 15 bushels.

Plat 10*a*, with ammonium salts alone each year, gave, over the first twenty years, an average of 22½ bushels per acre per annum; over the second twenty, 17¾ bushels, and over the forty years, 20⅛ bushels. Thus, ammonium salts alone produced much more than mineral manure alone.

To plat 10*b*, previous to 1852, in the years 1844, 1848, and 1850, mineral manures had been applied. In the other years previous to 1852 (excepting in 1846, when it was unmanured), and each year subsequently, ammonium salts alone were applied, and the effect of the residue of the mineral manures applied in the early years is apparent on comparison with the yields on 10*a*.

Thus, on plat 10*b*, over the first period of twenty years, there was an average annual yield of 25⅞ bushels per acre, against only 22½ bushels on 10*a*; over the second twenty years 19 bushels, against 17¾ on 10*a*; and over the forty years, an average of 22½ bushels, against only 20⅛ on 10*a*. For further comparison of plats 10*a* and 10*b*, especially in regard to the manuring during the first eight years, see the last two columns of Table 47 (p. 146), as well as Table 51 (p. 158).

Plat 11, with the ammonium salts and superphosphate (but no potash), gave, over the first twenty years, an average of 28 bushels per acre; over the second twenty, 22¼ bushels, and over the forty years, 25⅛ bushels.

On plat 12, in addition to the ammonium salts and superphosphate, sulphate of soda was applied, but the plat had received potash prior to 1852. The first twenty years after 1852 produced an average of 33⅞ bushels per acre, the second twenty of 27½ bushels, and the whole forty years of 30¾ bushels.

To plat 13, besides the ammonium salts and superphosphate, sulphate of potash was applied each year of the forty, and it had also received potash previously. The average annual produce was, over the first twenty of the forty years, 33⅞ bushels; over the second twenty, 29⅝, and over the forty years, 31¾ bushels.

On plat 14, besides the ammonium salts and superphosphate, sulphate of magnesia was applied; and, as on plats 12 and 13, some potash had been applied prior to 1852. The average annual produce was, over the first twenty of the forty years, 33⅞ bushels; over the second twenty, 28⅞ bushels, and over the forty years, 31⅜ bushels.

On plat 7, in addition to the ammonium salts and superphosphate, sulphates of potash, soda, and magnesia were applied; and there was an average annual yield during the first twenty years of 35¼ bushels per acre, during the second twenty of 31 bushels, and during the whole forty years of 33⅛ bushels.

It will be observed that in the case of every one of the plats to which Table 51 refers, and which we have just been considering, the produce is less over the second than over the first twenty years of the forty. Reference to Tables 48 (p. 150) and 47 (p. 146) will show that this was also the case with the produce of every other plat in the field. It was so on plat 7 with the most complete artificial manure; and it was so on plat 2 with farmyard manure every year, and great accumulation of manure residue from year to year. It is obvious, therefore, that the decline over the latter half of the forty years is by no means to be attributed exclusively to exhaustion. Reference to the details in the body of the tables and to the summaries at the bottom of them will show that there were a good many seasons of considerably less than average produce during the second twenty years of the forty, and that there were some very bad ones, especially in the fourth period of eight years, so that it is to less favorable seasons that the decline in yield over the latter half of the period must in many cases be largely attributed. Nevertheless, there can be no doubt that exhaustion has had a considerable share in the result in the case of many of the plats.

Comparing the produce on plats 12, 13, and 14 with that on plat 11 without potash, the effect not only of the direct supply, but of a residue from long previous applications of potash is clearly shown; but the deficiency with residue only compared with the produce with annual supply of potash is very evident during the later periods.

Both the amount and the limitation of the effect of the residue, compared with the annual supply of potash are strikingly illustrated by the results in Table 52 (p. 161). There are there given the amounts in pounds per acre of potash, soda, and phosphoric acid removed in the grain, in the straw, and in the total produce (grain and straw together), of plats, 11, 12, 13, and 14 above referred to, during each of the four ten-yearly periods of the forty.

TABLE 52.—*Potash, soda, and phosphoric acid (per acre per annum) in grain, in straw, and in total produce, of wheat, forty years, 1852–1891.*

Plat 11. Ammonium salts = 86 pounds nitrogen, and superphosphate.
Plat 12. Ammonium salts = 86 pounds nitrogen, superphosphate and soda (potash previous to 1852).
Plat 13. Ammonium salts = 86 pounds nitrogen, superphosphate and potash (potash previous to 1852).
Plat 14. Ammonium salts = 86 pounds nitrogen, superphosphate and magnesia (potash previous to 1852).

	In grain.				In straw.				In total produce.			
Plats	11.	12.	13.	14.	11.	12.	13.	14.	11.	12.	13.	14.
POTASH.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
10 years, 1852–61	9.3	11.4	11.3	11.3	21.6	34	41.9	38.5	30.9	45.4	53.2	49.8
10 years, 1862–71	8.8	11.4	12.2	11.6	17.2	26.4	43	27.5	26	37.8	55.2	39.1
10 years, 1872–81	6.8	8.2	9.1	8.4	11.5	18.3	31.7	18.8	18.3	26.5	40.8	27.2
10 years, 1882–91	7.1	9.3	10.6	9.8	11.1	21.1	40	21.3	18.2	30.4	50.6	31.1
40 years, 1852–91	8	10.1	10.8	10.3	15.4	25	39.6	26.5	23.4	35.1	50.4	36.8
SODA.												
10 years, 1852–61	.03	.07	.04	.06	1.54	.90	.36	.56	1.57	.97	.40	.62
10 years, 1862–71	.07	.07	.05	.04	2.40	1.70	.11	1.07	2.47	1.77	.16	1.11
10 years, 1872–81	.04	.04	.03	.05	1.35	1.15	.24	.84	1.39	1.19	.27	.89
10 years, 1882–91	.04	.03	.04	.04	.65	.82	.05	.47	.69	.85	.09	.51
40 years, 1852–91	.05	.05	.04	.05	1.48	1.14	.19	.74	1.53	1.20	.23	.78
PHOSPHORIC ACID.												
10 years, 1852–61	14.9	17.7	17.7	17.9	5	5.5	5.2	5	19.9	23.2	22.9	22.9
10 years, 1862–71	13.6	17	18.2	17.6	4.4	4.8	5.1	4.8	18	21.8	23.3	22.4
10 years, 1872–81	11.4	13.5	15.1	14	3.9	4.3	4.9	4.5	15.3	17.8	20	18.5
10 years, 1882–91	10.9	14.2	16.1	14.9	4.8	5.2	5.8	5.5	15.7	19.4	21.9	20.4
40 years, 1852–91	12.7	15.6	16.8	16.1	4.5	5	5.3	5	17.2	20.6	22	21.1

As the description above the table shows, each of the four plats, 11. 12, 13, and 14, received annually during the forty years, 1852–1891, inclusive, ammonium salts=86 pounds nitrogen per acre, and also superphosphate each year. Plat 11 received no potash during the forty years, nor any during the eight preceding years of the experiments. Plat 12 received no potash during the forty years, but a soda salt instead; it had, however, received 587 pounds of potash per acre during the eight preceding years. Plat 13 received a liberal supply of potash in each year of the forty, and it had received 737 pounds during the preceding eight years. Lastly, plat 14 received no potash during the forty years, but a magnesia salt instead; but it had received 566 pounds of potash during the preceding eight years. Thus, plat 11 received no potash throughout the forty-eight years; plat 12 none during the forty years, but there would be a residue from the applications during the preceding eight years. Plat 13 received potash every year of the forty, and a considerable quantity during the preceding eight years also; and plat 14 none during the forty years, but had a residue from previous applications.

Complete analyses of the ash of the grain, and of the straw, representing the produce of each of the four successive ten-yearly periods of the forty, of each of the four plats, have been made. We have, therefore, in the comparison of the amounts of potash in the crops of plats 12 and 14, with only residues of it from long previous applications, with those on plat 11, without any supply at all, and on plat 13, with both

residue and an annual supply of it, the means of judging whether the residues from the applications during the preceding eight years had been effective.

Referring to the amounts of potash stored up in the total produce (grain and straw together), the table shows that on plat 11, without any supply, the amounts in the crop per acre per annum were over the four ten-yearly periods 30.9, 26, 18.3, and 18.2 pounds, showing, therefore, a very great decline in the amount of potash in the crop where none had been supplied. On plat 12, with no supply during the forty years, but with residue from applications during the preceding eight years, the amounts in the crop per acre per annum over the successive periods were 45.4, 37.8, 26.5, and 30.4 pounds; that is, very much more than without any supply at all. On plat 14, again, without annual but with residual supply, the amounts in the crops were 49.8, 39.1, 27.2, and 31.1 pounds, or even rather more than on plat 12 with residual supply only. Lastly, the amounts of potash in the crops on plat 13, with both annual and residual supply, were 53.2, 55.2, 40.8, and 50.6 pounds, or very much more than on either of the plats with residual supply only. Or, if we take the average amounts of potash in the crops per acre per annum over the forty years, they were: On plat 11, without any supply, 23.4 pounds; on plat 12, with only residue from previous applications, 35.1 pounds; on plat 14, also with only residue, 36.8 pounds, but on plat 13, with liberal both previous and annual supply, 50.4 pounds. That is to say, there was about one and one-half times as much stored up in the total produce over the forty years where there was accumulation from previous applications as where none had been supplied, and more than twice as much where there had been full annual supply. The evidence is clear, therefore, that the residue from potash applied before the commencement of the forty years had been available to the succeeding crops. Indeed, according to calculations showing the balance of supply and removal, it would seem that the whole of the potash residues from the previous applications to plats 12 and 14 were, at the end of the succeeding forty years, approximately exhausted. It may be added that the Rothamsted experiments afford somewhat similar evidence in regard to phosphoric acid; and both constituents seem to be retained comparatively near the surface of the soil.

It will be remembered that in the case of some of the experimental barley plats we were enabled to correlate the results of the analyses of the ashes of the crops with those of determinations of potash in the soils made by different solvents by Dr. Bernard Dyer (see Table 29, p. 78, and discussion thereof), and that the inquiry proved to be of very much interest. It may be added, that Dr. Dyer is submitting samples of the soils from the above four plats, among others, in the experimental wheat field, to similar investigation, and the results will doubtless prove very instructive.

Detailed examination of the other columns in Table 52 (p. 161) relating to the potash will show that there is much less difference in the amounts of it in the grain of the different plats than in that of the straw. Thus, excluding plat 11, where there was no supply, and the produce suffered considerably even early in the forty years, it is seen that the average amounts of potash per acre per annum in the grain were, on plats 12 and 14, with only residual supply 10.1 and 10.3 pounds, against only 10.8 pounds on plat 13 with full supply. The average annual amounts in the straw were, however, 25 and 26.5 pounds with residual supply, against 39.6 pounds on plat 13 with full annual supply. It would thus seem that while the plant is in its vegetative stages, it takes up potash largely in proportion to the available supply of it—and it may be in excess of actual requirement if there be abundant supply; while, if there be no actual deficiency, the composition of the final product—the seed—is essentially uniform.

Referring to the columns relating to soda, it is seen that considerably smaller amounts were found in the produce of wheat than in that of barley. But, as in the case of the barley, the quantities of soda per acre in the total crop were greater where there was a marked deficiency of potash than where soda was actually supplied, while the smallest amounts were where the supply of potash was the greatest. Probably the greater amount of soda taken up by the barley than by the wheat is connected with the less root range, and much shorter period of collection in the case of the spring-sown crop. In both crops by far the greater proportion of the soda is found in the straw; but there is more in the grain of barley than in that of wheat, due doubtless to the paleæ or chaff being adherent and included with the grain in the case of the barley, but not in that of the wheat.

With regard to the phosphoric-acid results, as superphosphate was applied equally to all four plats, the difference in the amounts taken up and retained are obviously not due to differences of available supply, but are connected with the differences in the amounts of produce due to the supply or deficiency of other constituents. As in the case of the barley, by far the greater part of the phosphoric acid of the whole plant is accumulated in the grain, but the proportion remaining in the straw is greater in the wheat than in the barley.

Reference to the details in Table 52 (p. 161) will show that generally, and even where there was full supply, there was less of both potash and phosphoric acid in the crops over the third than over the fourth period of ten years, a result doubtless due to the third period including a more than average proportion of unfavorable seasons, as already referred to when considering the amounts of produce.

We have thus traced the effects of exhaustion and of full manuring, of nitrogenous and of nonnitrogenous manures on one particular soil. It has been seen how very different was the effect of one and the same manuring in different seasons; but the real extent of this variation is

more clearly brought out in Table 53, which shows the amounts of produce in the best and in the worst seasons of the forty years, and the average produce over the whole period under very opposite conditions as to manuring.

TABLE 53.—*Wheat year after year on the same land—Produce of the best season, 1863; of the worst season, 1879; and the average of forty years, 1852–1891.*

Plat number.	Description of manures (quantities per acre).	Dressed grain (per acre).			
		Best season, 1863.	Worst season, 1879.	Difference.	Average, 40 years, 1852-91.
		Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
3	Unmanured	17¼	4¾	12½	13
2	Farmyard manure	44	16	28	34⅞
5	Mixed mineral manure alone	19⅝	5⅝	14	15
6	Mixed mineral manure and 200 pounds ammonium salts = 43 pounds nitrogen	39⅝	10½	29⅛	24½
7	Mixed mineral manure and 400 pounds ammonium salts = 86 pounds nitrogen	53⅝	16¼	37⅜	33⅛
9	Mixed mineral manure and 550[1] pounds nitrate soda = 86 pounds nitrogen	55⅝	22	33⅝	35⅜
8	Mixed mineral manure and 600 pounds ammonium salts = 129 pounds nitrogen	55¾	20⅝	35⅛	36½

[1] 275 pounds nitrate of soda = 43 pounds nitrogen, 1885, and since.

It will suffice to confine attention to the amount of dressed grain per acre, in bushels. The difference in yield of the various plats in the best and worst of the forty seasons is very striking. The unmanured, the mineral manured, and the heavily nitrogenous manured plats all suffered severely in the bad season. In most cases the difference between the produce of the best and the worst season approached, and in two (plats 6 and 7) it actually exceeded, the average produce of the plats. From these facts it will be seen how easy it is to form wrong conclusions as to the effects of different manures, if experiments are conducted in one season only, or in only a few seasons, and if the characters of the seasons are not studied.

Not only season, but soil and locality also, must exercise an influence. The Rothamsted results are, of course, obtained on one description of soil, and in one locality. Reference to the following table (54) will show the results obtained in experiments conducted at Rothamsted, during the same eight years in two different fields; at Woburn, for seven years; at Holkham, Norfolk, for three years; and at Rodmersham, Kent, for four years.

TABLE 54.—*Results of experiments on the growth of wheat by different manures, on different soils, in different localities, and in different seasons.*

Manures (quantities per acre).	Dressed grain (per acre).					
	Rothamsted.			Woburn beds, 7 years, 1877–83.	Holkham, Norfolk, 3 years, 1852–54.	Rodmersham, Kent, 4 years, 1856–59.
	8 years, 1856–63.		40 years, 1852–91.			
	Broadbalk field.	Hoosfield.	Broadbalk field.			
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Unmanured	16	15	13	$15\frac{7}{8}$	18	$25\frac{5}{8}$
Mixed mineral manure alone	19	$16\frac{1}{8}$	15	$16\frac{7}{8}$	$19\frac{1}{8}$	$28\frac{1}{2}$
Ammonium salts alone = 86 pounds nitrogen	$23\frac{1}{4}$	$26\frac{1}{8}$	$21\frac{3}{8}$	[1] $23\frac{5}{8}$	$27\frac{1}{4}$	$31\frac{1}{2}$
Mixed mineral manure and ammonium salts = 86 pounds nitrogen	$38\frac{1}{2}$	$37\frac{3}{8}$	$33\frac{1}{8}$	$37\frac{5}{8}$	$32\frac{5}{8}$	$33\frac{1}{2}$

[1] By ammonium salts = only 43 pounds nitrogen.

Thus, in experiments made on very various soils, in different conditions from previous treatment, and in various seasons, the general character of the results obtained with each of the four very different conditions as to manuring was accordant. The only marked exception was in the case of Rodmersham, Kent, where the condition of the land was admittedly higher than was suitable for experiments with different manures. Accordingly, the produce without manure, with mineral manure alone, and with ammonium salts alone, was higher than that obtained under the same manurial conditions in either of the other localities; whilst the produce of grain with the highest manuring, that is, with the mineral manure and ammonium salts together, was comparatively low, the crop having been over luxuriant, with an excessive proportion of straw.

SUMMARY AND GENERAL CONCLUSIONS.

It has been shown that root crops may be grown for many years in succession on ordinary arable land, provided a proper tilth be maintained, and suitable manures are applied. Full crops of barley also have been grown for more than forty years in succession on such land. Leguminous crops, on the other hand—beans and clover, for example—entirely failed when it was attempted to grow them for many years in succession on ordinary arable land; though large crops of red clover have been obtained for forty years in succession on rich garden soil. Lastly, as shown by the results relating to wheat, it has been successfully grown for fifty years in succession, without manure, with farmyard manure, and with various artificial manures, on ordinary, and certainly not rich, arable land. The unmanured and the farmyard manure plats have, respectively, been treated exactly in the same way in each of the fifty years. The artificially manured plats, however, as a rule did not receive the same manure from year to year during the first eight years, 1844–1851; but, with a few special exceptions, each has been treated uniformly during the forty-two years, 1852–1893, inclusive.

Accordingly, most of the comparisons that have been drawn refer to the period of forty years, 1852–1891.

Referring first to the results obtained on the farmyard manure plat, the average annual produce over the forty years was $34\frac{7}{8}$ bushels, and over the fifty years $33\frac{1}{2}$ bushels; in the one case nearly 7 bushels and in the other $5\frac{1}{2}$ bushels more than the average of the United Kingdom under ordinary rotation; in both not far short of three times the average produce of the United States, and more than two and one-half times the average of the whole of the wheat lands of the world.

Without any manure whatever the average annual produce was 13 bushels over the forty, and $13\frac{1}{2}$ bushels over the fifty years; in both cases more than the average of the United States under ordinary cultivation, including their rich prairie lands, and about the average of the whole world.

The results on the artificially manured plats show that mineral manures alone gave very little increase of produce; that nitrogenous manures alone gave considerably more than mineral manures alone; but that mixtures of the two gave very much more than either separately. In two cases the average produce by mixed mineral and nitrogenous manure was more than that by the annual application of farmyard manure; and in nine out of the twelve cases in which such mixtures were used the average yield per acre was from 2 to 8 bushels more than the average yield of the United Kingdom (nearly 28 bushels) under ordinary rotation.

Such were the results obtained for forty or fifty years in succession on ordinary arable land; and that the soil is not a rich one may be judged by the low percentage of nitrogen found in the surface and subsoil.

As bearing upon the question of the yield of wheat of different soils and different countries, it will be of interest to contrast the condition of soils of very different history in relation to their percentage of nitrogen, and, where practicable, of carbon also. Table 55 shows the characters in these respects—of arable soil under rotation and in fairly good condition; of that of the experimental wheat field variously manured; of exhausted arable soils; of newly laid down permanent grass land, and of old grass land at Rothamsted. It also gives results relating to some other old arable soils; to some United States and Canadian prairie soils; and, lastly, to some rich Russian soils.

TABLE 55.—*Nitrogen and carbon in various soils.*

	Date of soil sampling.	In dry sifted soil.[1] Nitrogen.	Carbon.	Carbon to 1 nitrogen.	Authority.
ROTHAMSTED ARABLE AND GRASS SOILS.		*P. ct.*	*P. ct.*		
Four-course rotation, 1848 and since, fully manured for roots, each course	1867, after wheat	0.1402	....	....	Rothamsted.
	1874, after clover	.1372	....	....	Rothamsted.
	1883, after wheat	.1391	....	....	Rothamsted.
Wheat, 1843–44 and each year since:					
Farmyard manure, every year	October, 1865	.1882	1.836	9.8	Rothamsted.
	October, 1881	.1957	2.294	11.7	Rothamsted.
Mineral and nitrogenous manure	October, 1865	.1230	1.180	9.6	Rothamsted.
	October, 1881	.1264	1.341	10.6	Rothamsted.
Mineral manure alone	October, 1865	.1119	1.039	9.3	Rothamsted.
	October, 1881	.1012	1.080	10.7	Rothamsted.
Unmanured	October, 1865	.1090	.978	9	Rothamsted.
	October, 1881	.1045	1.017	7	Rothamsted.
Barley, 1852, and each year since; mineral manures alone	March, 1868	.1202	....	....	Rothamsted.
	March, 1882	.1124	1.154	10.3	Rothamsted.
Roots, 1843–52; barley, 1853–55; roots, 1856–69; mineral manures alone.	April, 1870	.0934	....	....	Rothamsted.
Arable laid down to grass (10 acres), spring, 1879.	February, 1882	.1235	....	....	Rothamsted.
Arable laid down to grass (Barnfield), spring, 1874.	do	.1509	....	....	Rothamsted.
Arable laid down to grass (apple tree field), spring, 1863.	November, 1881	.1740	....	....	Rothamsted.
Arable laid down to grass (Dr. Gilbert's meadow), spring, 1858.	January, 1879	.2057	2.412	11.7	Rothamsted.
Arable laid down to grass (high field), spring, 1838.	September, 1878	.1943	2.403	12.4	Rothamsted.
Very old grass land (the park)	February and March, 1876.	.2466	3.377	13.7	Rothamsted.
VARIOUS ARABLE SOILS IN GREAT BRITAIN.					
Mr. Prout's farm:					
Broad field (surface)	....	.170	....	....	Voelcker.
Black acre (surface)	....	.107	....	....	Voelcker.
White moor (surface)	....	.171	....	....	Voelcker.
Wheat soils:					
Midlothian	....	.22	....	....	Anderson.
Eastlothian	....	.13	....	....	Anderson.
Perthshire	....	.21	....	....	Anderson.
Berwickshire	....	.14	....	....	Anderson.
Red sandstone soil, England	....	.18	....	....	Voelcker.
UNITED STATES AND CANADIAN PRAIRIE SOILS.					
United States—Illinois:					
No. 1	....	.30	....	....	Voelcker.
No. 2	....	.26	....	....	Voelcker.
No. 3	....	.33	....	....	Voelcker.
No. 4	....	.34	....	....	Voelcker.
Canada:					
Manitoba, Portage la Prairie (surface).	....	.247	....	....	Rothamsted.
Northwest Territory; Saskatchewan district (surface).	....	.303	....	....	Rothamsted.
Northwest Territory; 40 miles from Fort Ellice (surface).	....	.250	....	....	Rothamsted.
Manitoba—					
Niverville, (first 12 inches)	....	.261	3.42	13.1	Rothamsted.
Brandon (12 inches)	....	.187	2.66	14.2	Rothamsted.
Selkirk (12 inches)	....	.618	7.58	12.3	Rothamsted.
Winnipeg (12 inches)	....	.428	5.21	12.2	Rothamsted.
RUSSIAN SOILS.					
No. 1 (12 inches)	....	.607	....	....	C. Schmidt.
No. 2 (8 inches)	....	.467	....	....	C. Schmidt.
No. 3 (5 inches)	....	.188	....	....	C. Schmidt.
No. 4 (6 inches)	....	.130	....	....	C. Schmidt.
No. 5 (11 inches)	....	.305	....	....	C. Schmidt.
No. 6 (17 inches)	....	.281	....	....	C. Schmidt.
No. 7 (9 inches)	....	.409	....	....	C. Schmidt.

[1] Calculated on soil dried at 100° C.

Unfortunately, in the early years of the Rothamsted experiments samples of soil were not taken of a fixed area and to a fixed depth, so that the results of nitrogen determinations in them are not comparable

with those taken at later dates to the uniform depth of 9 inches. It is difficult, therefore, accurately to estimate the percentage of nitrogen in the wheat field surface soil at the commencement of the experiments. Some idea may, however, be formed from the results given in the table. Thus it is seen that in a field which, from 1848 up to the present time, has been under four-course rotation of roots (fed on the land), barley, leguminous crop, and wheat, with mineral and nitrogenous manure for the roots commencing each course, the percentages of nitrogen in the dry sifted soil were: In 1867, after the fourth crop since manuring (wheat), 0.1402; in 1874, after the third crop since manuring (clover), 0.1372 per cent, and in 1883, again after the fourth crop (the wheat), 0.1391 per cent. Here then, under rotation and liberal manuring and the feeding of the roots on the land, the average percentage of nitrogen in the surface soil is maintained at nearly 0.140. Then, referring to the results obtained in the wheat field itself, it is seen that after growing wheat with full mineral and nitrogenous manure since 1843–44, the percentage of nitrogen in the dry sifted surface soil was: In 1865, 0.1230, and in 1881, 0.1264; but, with mineral manure without nitrogen, it was, in 1865, only 0.1119, and in 1881, 0.1012 per cent; and lastly, without manure from the commencement, it was, in 1865, only 0.1090, and in 1881, 0.1045 per cent. That is to say, with mineral and nitrogenous manure the percentage of nitrogen was the highest, and rather higher at the later than at the earlier date; the result being due, as has been proved, not to the accumulation of manure residue, but of crop residue. On the other hand, with mineral manure without nitrogen, or without any manure at all, the percentage of nitrogen was lower than when nitrogenous manure was also used; and in each case it was lower at the later date, that is, as the exhaustion progressed.

On a consideration of these various results it may perhaps fairly be concluded that the percentage of nitrogen in the surface soil of the wheat field at the commencement was certainly higher than in 1865 or 1881, under the conditions of nitrogen exhaustion with mineral manure alone, or without any manure at all; and that it was about as high as where nitrogenous as well as mineral manure had been annually applied; probably, therefore, from 0.1250 to 0.1300 per cent, and probably nearer the lower than the higher figure.

Looking to the other results in the table relating to Rothamsted soils, it is seen that with barley, as with wheat, when grown year after year with mineral manures alone, the percentage of nitrogen in the surface soil was low, with a tendency to decline from time to time; and lastly, after roots grown with mineral manure alone, the percentage is lower still; indeed, lower than has been found where any other crop has been grown under similar conditions. Then, it is further seen that in the case of various arable fields laid down to permanent grass, the percentage of nitrogen increased more or less, according to the time it had been laid down, the figures at the different periods being 0.1235, 0.1509,

0.1740, 0.2057, and 0.1943, whilst the percentage in very old grass land was 0.2466.

Next, in various arable soils in Great Britain, the percentage of nitrogen in the surface soils ranged from 0.107 to 0.220. Compared with these, the percentage in various United States and Canadian prairie soils ranged from 0.187 to 0.618, the greater number showing about 0.30 per cent. Lastly, a number of Russian soils ranged in percentage from 0.130 to 0.607. It is further seen that the percentages of carbon, and the amount of carbon to 1 of nitrogen, are higher in the grass land than in the arable soils, and higher still in the rich prairie soils.

From these various results there can be no doubt that a characteristic of a permanent grass surface soil, or of a rich virgin soil, is a relatively high percentage of nitrogen and of carbon, and a high relation of carbon to nitrogen. On the other hand, a soil that has been long under arable culture is much poorer in these respects, whilst arable soils under conditions of known agricultural exhaustion show a very low percentage of nitrogen and of carbon and a low relation of carbon to nitrogen.

It has sometimes been maintained that a soil is a laboratory and not a mine. But not only the facts ascertained in our own and in other investigations, but the history of agriculture throughout the world so far as it is known, clearly show that a fertile soil is one which has accumulated within it the residue of long periods of previous vegetation, and that it becomes infertile as this residue is exhausted. Such accumulations are truly enormous in many of the prairie lands of the American continent, sometimes indeed extending to a considerable depth. But, even after the comparatively few years which most of them have been under cultivation, it is alleged by some that they are already showing exhaustion.

In view of the facts both as to the percentage of nitrogen, and the annual yield of wheat without manure over forty or fifty years in the Rothamsted experimental field, it is indeed very difficult to believe that the rich prairie lands of the American continent, which yield so large a proportion of the wheat exported from the United States and Canada, can in so much less a time have become exhausted of available nitrogen. Thus, it is probable that at the commencement the surface soil of none of these lands contained less than twice, and few of them less than three times, as high a percentage of nitrogen as the Rothamsted wheat-field soil, whilst frequently the subsoils would, to a considerable depth, be richer than the Rothamsted surface soil. Yet it is estimated that over a period of forty years from 1852 to 1891, inclusive, the produce of the Rothamsted soil without manure has only reduced by an average of about one-sixth bushel per acre per annum due to exhaustion, irrespectively of fluctuations due to season; and when we consider how much shorter a time most of the rich prairie lands have been growing wheat without manure, it seems that some other reason than exhaustion must be found for their alleged reduction in yield.

As to the number of years during which the greater portion of the rich prairie lands of America have been broken up for the growth of wheat, it may be observed that a series of unproductive seasons, not only in our own country but in western Europe generally, which culminated in 1879 but continued for some years later, led to a more rapid reduction in our own area under the crop, and concurrently to the opening up of large wheat-growing areas in various parts of the world, and at the same time to greatly increased imports, a much larger amount coming from the United States than from any other country, indeed, generally more than from all other countries put together. Thus, the area under wheat in the United States increased from under 21 million acres in 1872 to more than 27½ million in 1876, with an average for the five years of nearly 24½ million. Over the next five years the area increased from 26¼ million in 1877 to 37¾ million in 1881, with an average over the five years of 33⅓ million. Over the next ten years from 1882 to 1891, the area averaged 37⅓ million acres, and in 1892 it was more than 38½ million. There was an increase, therefore, from less than 21 million in 1872 to an average of 37⅓ million over the ten years ending 1891, or by about 79 per cent. In fact, this great increase in the area under the crop has taken place within a period of about twenty years, the actual increase during that period amounting to about 16½ million acres, by far the greater proportion of which is rich prairie land. Of this the larger proportion has been brought under cultivation within a period of about fifteen years. Bearing in mind the results obtained at Rothamsted without manure for fifty years, on a comparatively very poor soil, it does indeed seem incredible that a period of about fifteen years should be sufficient to bring about palpable exhaustion of the incomparably richer prairie soils.

Within the same period of twenty years the home consumption of wheat in the United States has, according to the records, increased from rather under 200 million Winchester bushels in 1872–73 to an average of nearly 334 million over the ten years from 1882–83 to 1891–92, whilst the exports have increased from 52½ million bushels in 1872–73 to an average of 146½ million over the five years 1877–78 to 1881–82, but amounted to an average of rather less than 130 million over the ten years 1882–83 to 1891–92. The maximum amount in any one year was, however, 227½ million in 1891–92, and in 1892–93 the amount was 192½ million bushels.

It has been estimated that, judging from the increase of the population of the United States in the past, the Central, Northern, and Western States, from which we now derive such large supplies of grain, will, before many years have passed, be as densely populated as the Eastern States are now, and that then the export of grain will be rapidly diminished. In this calculation, however, the essential difference in the character of the land in the Eastern States and in the prairie districts of the Central, Northern, and Western States, is not

taken into account. It is true that both Western meat and Western wheat are materially reducing their production in the Eastern States; so that the population of the East, as well as of the West, will consume more and more of the Western produce, leaving, of course, the less for export. And if, in addition to this, it be true as alleged, that the Western lands themselves are losing their fertility, there would, indeed, seem that there is some likelihood of material reduction in exports before very long.

Certain it is, however, that large areas of formerly prairie land which provide so much of the exports, were originally as rich as plowed-up old grass-land in our own country, and sometimes so to a considerable depth. Hitherto the land has, as a rule, only been skimmed, practically no labor bestowed on cleaning, and compared with the produce which such lands should yield if properly cultivated very small crops of grain have been obtained. But the large crops occasionally yielded under favorable conditions are evidence of the inherent fertility and of the possible productiveness of the soil. Further, from what has been said, it is almost impossible to believe that such soils can have become seriously exhausted within comparatively so few years; at any rate, so far as available nitrogen is concerned. Indeed, if there be palpable exhaustion at all, it would seem more likely that it is of some mineral constituents—potash, lime, or phosphoric acid, for example. However this may be, so long as wheat is grown under the conditions frequent, and indeed almost inevitable, in the case of new settlement, with sparse population—that is, growing it for several years in succession, with deficient cultivation, luxuriance of weeds, the burning of the straw, and generally the wasting of the manure of the working stock—only low yields can be expected. The practice naturally results from the fact that under such conditions fertility is cheap and labor dear. As population becomes more dense, however, local markets will arise for rotation products, more stock will be kept, the straw and the manure will be utilized, cultivation will be improved, and weeds will lose their ascendency. Nor can there be much doubt that, under such conditions, it will be found that the growth of comparatively small crops of wheat, even with a fair share of weeds, for fifteen or twenty years on rich prairie land has not exhausted its fertility. There will, besides, for some time to come, be more rich prairie land to bring under the plow. Upon the whole, it seems probable that, with the improved methods which should result from increased density of population, and with the increased areas brought under cultivation, it will be longer than is sometimes supposed before the capability of the United States of production for export will be materially diminished. Obviously, somewhat similar arguments are, *mutatis mutandis*, applicable to Canada. As, however, the resources of the rest of the world, taken as a whole, show no signs of diminution, it may be a question, how far the range of prices will affect the production in any particular country.

SECTION V.

ROTATION OF CROPS.

INTRODUCTION AND HISTORICAL SKETCH.

In the preceding sections attention has been devoted to the consideration of the influence of exhaustion, manures, and variations of season on the amounts of produce and on the composition of certain individual and typical crops when each is grown separately year after year on the same land. In this way there have been discussed the characteristic requirements and results of growth of various cereal crops as members of the order Gramineæ, of various root crops of the orders Cruciferæ and Chenopodiaceæ, and lastly of various leguminous crops.

Our subject now is rotation of crops, a practice which is admitted to be the foundation of the improvements in our own agriculture which have taken place during this and a considerable part of the last century. It is of great importance, therefore, carefully to consider both in what the practice itself consists and how its benefits are to be explained.

If I had to define the practice of rotation of crops as followed in our own country, indeed over large portions of Europe, in the fewest possible words, I should say that it consists in the alternation of root crops and of leguminous crops with cereals. In the United States, however, it is a gramineous crop (maize) which largely takes the place of root crops in Europe.

The cereals constituting such a very important element of human food, it was natural that they should be grown almost continuously so long as the land would yield remunerative crops. Hence, the history of agriculture, not only in our own country, but in others where these crops were of high relative value, shows that it very generally came to be the custom to grow them for a number of years in succession and then to have recourse to bare fallow, or in some cases to abandon the land to the growth of rough and weedy herbage, affording scanty food for domestic animals.

The improvement upon these practices attainable by alternating other crops with the cereals was very much earlier recognized in the case of the leguminous than of the root crops, the introduction of which is of comparatively recent date.

It was, in fact, distinctly recognized by the Romans more than two thousand years ago that certain leguminous crops were not only valuable as food for animals, but that their growth enriched the soil for succeeding crops; in fact that they were of value as restorative crops grown in alternation with the cereals. There is, however, very scanty indication that root crops were an element in their alternate cropping.

As in the agriculture of the ancients, so in that of more modern times, especially in our own country, various leguminous crops were grown in alternation with cereals long before roots were so interpolated It was, indeed, not until about or after 1730, that Lord Townshend, who, as secretary to George I, had been in Hanover, and there seen turnips growing as a field crop, on his return introduced them on his own estate in Norfolk, and there founded the celebrated Norfolk four-course rotation of turnips, barley, clover, and wheat. His own land was previously, to a great extent, a marshy or sandy waste, and its value was increased enormously under the new system. It was, however, not until toward the end of the century that it became generally adopted even throughout his own county. In this extension, Mr. Coke, of Holkham (afterwards Earl of Leicester), was largely instrumental, and the practice seems to have next extended into Lincolnshire.

It was thus that the four-course rotation, or in other words the alternation of root-crops and of leguminous crops with cereals, became established. Such alternation is, in fact, the basis of all the various rotations which are adopted in different parts of our own country, and also to a great extent which are followed in many other countries.

It is worthy of remark that although we owe the introduction of the essential elements of our rotations to the example of our continental neighbors, we, with one or two immaterial exceptions, obtain more per acre of all the staple saleable products of rotation—grain and meat—under our landlord, tenant, and laborer system than any other country in Europe, or than in America, under whatever advantages of climate, or under whatever system of holding, or of size of holdings. Thus there is not a single country in Europe that reaches our average produce per acre of wheat; only Belgium and Holland approach, but they do not equal us in the produce of barley; only Belgium, Holland, and Norway exceed us in acreage yield of oats; and no country approaches us in acreage produce of potatoes. Again, whilst several countries exceed us in number of cows to a given area, and some in the number of pigs, not one equals us in weight per acre of other cattle than cows; and not one nearly approaches us in the weight of sheep to a given area. Nor, notwithstanding the great depression of our agriculture in recent years—the result of the low prices of produce—is there any probability that we shall soon lose our preeminence in production per acre.

There can be no doubt that the effect of the extension of the growth of green crops was, to a great extent, to get rid of unprofitable fallows, greatly to increase the supply of stock food, especially for winter feeding, so to lead to a largely increased production of meat and milk, to a greatly increased supply of manure, and thus to enrich the land for the growth of grain, which, accordingly, yielded much larger crops.

We have now to endeavor to ascertain how the admittedly very beneficial effects of alternate, as distinguished from continuous, cropping are to be explained. It will be well first very briefly to refer to some

of the chief theoretical explanations that have been put forward, and afterwards to discuss the results of various direct experimental investigations conducted at Rothamsted on the subject of rotation.

The first definite theory as to the benefits of the alternation of crops assumed that the excreted matters of one description of crop were injurious to plants of the same description, but that they were not so, and might even be beneficial to other kinds of plants.

At first Liebig pronounced this theory of rotation to be the only one having any really scientific basis. Later he seems to have modified his view considerably; and to have supposed that the explanation was, not that the excreted matters of one description of plant were injurious to another of the same description, but that, as the different plants had such very different mineral requirements, the alternation of one kind with another relieved the soil from exhaustion. In his latest work, however, after many years of controversy, he obviously more fully recognized that nitrogen probably played some important part in the matter.

More than fifty years ago Boussingault published the results of an investigation extending over a period of ten years, to determine the chemical statistics of some of the rotations actually followed in his own locality, in Alsace; and he came to the conclusion that the difference in the amounts of nitrogen taken up by the different crops constituted a very important element in the explanation of the benefits of rotation.

I will only further refer to the results and conclusions of the late Professor Daubeny, of Oxford, who commenced a series of experiments in the Botanic Garden there, in 1834. One of the original objects he had in view was to test the truth of De Candolle's theory, that the excretions of one description of plant were injurious to plants of the same description. He soon came to a negative conclusion on the subject, and recognized the validity of Boussingault's argument, that the actual facts of vegetation in different parts of the world conclusively showed that the same description of plant may continue to grow healthily on the same land for long periods of time. On this point it is scarcely necessary to add that the experience at Rothamsted on the growth of various agricultural crops, year after year, on the same land for many years in succession, is conclusive against the theory of injurious or poisonous excretions.

But, as already said, Dr. Daubeny continued his experiments for ten years; and, although in accordance with the prevailing ideas of the time, all his analytical results related to the mineral constituents of his soils and crops, his main conclusion was that the benefits of rotation were probably as much connected with the available supply of the organic as of the inorganic constituents.

What then are the indications of the results of many years of investigation of the subject, in the field and in the laboratory, at Rothamsted?

THE EXPERIMENTS ON ROTATION MADE AT ROTHAMSTED.

The experiments have been conducted in Agdell field. An area of 2½ acres is devoted to the purpose. The ordinary four-course rotation of turnips, barley, clover (or beans), or fallow, and wheat was adopted. The experiments were commenced in 1848, so that the eleventh course of four years each was completed with the harvest of 1891, and the barley of the present year (1893), is the second crop of the twelfth course, and concludes the forty-sixth year of the experiments.

The area of 2½ acres was divided into three main divisions, which have, respectively, been under the following conditions as to manuring: (1) Without manure from the commencement. (2) For the first nine courses, manured with superphosphate alone, applied only for the turnip crop commencing each course; that is, once every four years. For the tenth, and each subsequent course, salts of potash, soda, and magnesia have been applied as well as superphosphate. (3) A complex artificial manure, also applied every fourth year; that is, for the turnips, commencing each course. This manure comprises superphosphate, salts of potash, soda, and magnesia, ammonium salts, and rape cake; and it supplies about 140 pounds of nitrogen per acre for the four years' course; that is, an average of 35 pounds of nitrogen per acre per annum.

The complex manure was designed to be, in great measure, a substitute for farmyard manure; and it was used instead of it, in order that the amount of the different constituents supplied might be more accurately known than would have been the case if farmyard manure had been employed.

It should be further explained that when the land is under turnips the roots, with their leaves, are removed from one-half of each of the three differently-manured plats; whilst on the other half of each the produce is consumed on the land by sheep, or, if the weather be unsuitable for this, the roots are sliced, and both roots and leaves are spread on the land. Thus each of the three main divisions is divided into two, making so far six in all.

Then again, after the first course of four years, in the third year of each course the leguminous crop was grown on only half of each of the three differently-manured plats, and the other half was left fallow. Lastly, as clover can not be relied upon on such land so often as once in four years, beans have frequently been grown instead.

We have finally, therefore, twelve plats, instead of only three. That is, to say, each of the three differently-manured plats is divided into four, as above described, and as indicated in the heading of the several tables; and as the same form of table will as far as possible be adopted throughout, it is very desirable that a clear idea of the arrangement should be formed at the outset. It will be seen that under each of the three main divisions designated in the heading according to the manuring, the results are subdivided, showing first the produce obtained where the roots were carted from the land, and secondly, where they

were fed (or left) upon it. Lastly, under each of these two conditions, so far as the disposal of the turnips is concerned, there is again a subdivision into two—one where in the third year of the course the land was left fallow, and the other where either clover or beans was grown.

Each year the amount of produce on each of the various plats is weighed; samples of each crop are taken; in all, the dry substance and the mineral matter (ash), and in many the nitrogen, are determined; in many cases also complete analyses of the ashes of the crops have been made. Lastly, determinations of the total nitrogen have been made in the surface soils, and in the upper layers of the subsoils, at different periods; and the nitrogen as nitric acid has also been determined to a considerable depth. As to the results themselves, I can only very briefly refer to the main indications of these various investigations.

Tables 56, 57, 58, and 59 give the amounts of produce of the turnips, the barley, the leguminous crops, and the wheat, respectively, in each of the eleven years in which each was grown in the eleven completed courses. Each table is divided into three main divisions; the upper one giving the roots, or the grain, etc., as the case may be; the middle the leaves or the straw, and the lower one the total produce—roots and leaves, or grain and straw, together.

THE SWEDISH TURNIP CROPS.

Referring to Table 56, relating to the Swedish turnips, it is seen that in the first year, 1848, there was, both without manure and with superphosphate alone, much more produce than in any subsequent year; showing that, at the commencement, the land was in somewhat high condition, due to previous treatment. Then, again, as already said, for the tenth and eleventh courses salts of potash, soda, and magnesia were used as well as superphosphate. For these reasons the results of the first and the tenth and eleventh courses will be excluded from the averages to which I shall chiefly confine attention. In this table, however, as well as in those relating, respectively, to the barley and the wheat, averages are given at the foot of each division of the tables, not only for the eight intermediate courses, second to ninth, but also for the two succeeding courses, tenth and eleventh, for which potash, soda, and magnesia were used as well as superphosphate. But, for the leguminous crops, the averages are, for reasons that will be explained, taken differently.

TABLE 56.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eleven courses, forty-four years, 1848–1891).*

1. ROOTS—SWEDISH TURNIPS.

Years.	Unmanured.								Courses 1 to 9, superphosphate only; courses 10 and 11, mixed mineral manure.								Mixed mineral and nitrogenous manure.							
	Roots carted.				Roots fed.				Roots carted.				Roots fed.				Roots carted.				Roots fed.			
	Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.	
	Tons.	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
ROOTS.																								
1848	8	15¼	3	5½	8	17¾	5	9	14	12	11	5¾	17	5	11	0¾	19	14¾	10	18	21	9	11	9
1852	1	17	1	6	1	7¼	0	19½	12	16¾	11	3¼	13	13¼	12	10¼	20	8¼	19	16½	19	10¾	19	6
1856	2	5½	1	12	1	14	1	0¼	8	10½	6	16	9	13¾	9	16	16	8¼	16	13¾	16	19¼	17	1¼
1860	0	1¾	0	1	0	1½	0	1	1	13¾	1	9¼	2	0¾	1	18¾	4	7½	4	7½	4	7	3	12
1864	0	7½	0	8¾	0	9	0	8½	2	12¾	3	8	3	19½	3	18¾	9	2½	8	16¼	9	5½	8	8½
1868[1]																								
1872	2	11⅞	1	14⅛	2	9¼	1	9½	7	2¼	8	10⅝	8	7½	9	10½	16	12	16	19⅞	16	11¼	16	10
1876	1	11½	0	17¼	1	12¼	1	1	9	13¼	9	8¼	10	8¼	11	5¾	15	9¾	17	16	18	17¼	17	19¼
1880	1	12⅝	0	14	1	18¼	1	1	11	4	9	19½	11	18¾	11	3¾	22	10¼	21	19½	22	7¼	22	6¼
1884	0	17⅞	0	5	1	0¼	0	12	7	19¾	8	13¼	8	12½	10	6	14	18¼	14	6¾	14	16¼	14	0¾
1888	0	15	0	2¼	1	3	0	8	7	2¾	10	7	8	6	12	9¼	21	11¼	23	12¾	21	3¾	20	17½
Average: 8 courses, 1852 to 1880	1	6	0	16⅝	1	4	0	15⅛	6	14⅛	6	6⅞	7	10¼	7	10½	13	2⅜	13	6⅛	13	9¾	13	2⅞
Average: 2 courses, 1884 and 1888	0	16½	0	3⅝	1	1⅝	0	10	7	11⅜	9	10¼	8	9¼	11	7⅝	18	4¾	18	19¾	18	0	17	9¼
LEAVES.																								
1848	0	19¾	2	5¾	1	0½	3	7¾	1	15	5	6¼	1	19¾	4	10	2	6¼	7	11¾	2	6¾	7	11¼
1852	0	5¾	0	4¼	0	4	0	3¼	1	2¾	1	0¼	1	2¼	1	2	2	0	1	16½	1	17¾	1	13
1856	0	2¼	0	2½	0	2	0	1½	0	8	0	7½	0	12¼	0	14½	0	11½	0	12½	0	12½	0	11¾
1860	0	0⅛	(6¼ pounds.)		0	0¼	(5 pounds.)		0	2	0	1½	0	2	0	1¾	0	3½	0	3¼	0	5¾	0	4½
1864	0	0¾	0	0¾	0	0¾	0	1	0	4½	0	4¾	0	5¼	0	4¾	0	9	0	8¾	0	9½	0	8¾
1868[1]																								
1872	0	8⅛	0	8¾	0	7¼	0	7¾	0	14⅝	0	17⅜	0	17⅜	0	19½	1	14¼	1	15¾	1	13½	1	19
1876	0	5¼	0	5	0	5⅛	0	5	0	17	1	8½	0	16½	1	7½	1	14¾	2	15¼	2	0¾	3	3
1880	0	3⅞	0	2¼	0	4	0	3	0	12½	0	11¾	0	12⅞	0	11	1	16	2	3¼	1	18	1	18¾
1884	0	7⅜	0	3¼	0	7	0	5	0	18½	1	0¼	0	18¾	1	3	2	15¼	3	3¼	3	6¼	3	3¾
1888	0	7	0	1¾	0	7½	0	3¼	0	15¼	1	1½	0	16	1	3	1	17¾	2	5¾	1	15	2	0½

[1] Crop failed.

TABLE 56.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eleven courses, forty-four years, 1848–1891*—Continued.

1. ROOTS—SWEDISH TURNIPS—Continued.

Years.	Unmanured.								Courses 1 to 9, superphosphate only; courses 10 and 11, mixed mineral manure.								Mixed mineral and nitrogenous manure.							
	Roots carted.				Roots fed.				Roots carted.				Roots fed.				Roots carted.				Roots fed.			
	Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.		Fallow.		Beans or clover.	
LEAVES—continued.	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*	*Tons.*	*Cwt.*
Average: 8 courses, 1852 to 1880	0	3¼	0	3	0	2⅞	0	2⅝	0	10⅛	0	11½	0	11	0	12⅝	1	1⅛	1	4⅜	1	2¼	1	4⅞
Average: 2 courses, 1884 and 1888	0	7¼	0	2½	0	7¼	0	4⅛	0	16⅞	1	0⅞	0	17⅜	1	3	2	6½	2	14½	2	10⅝	2	12⅛
TOTAL PRODUCE.																								
1848	9	15	5	11¼	9	18¼	8	16¾	16	7	16	12	19	4¾	15	10¾	22	1	18	9¾	23	15¾	19	0¼
1852	2	2¾	1	10¼	1	11¼	1	2¾	13	19½	12	3½	14	15½	13	12¼	22	8¼	21	13	21	8½	20	19
1856	2	7¾	1	14½	1	16	1	1¾	8	18½	7	3½	10	6	10	10½	16	19¾	17	6¼	17	11¾	17	13
1860	0	1⅞	0	1	0	1¾	0	1	1	15¾	1	10¾	2	2¾	2	0½	4	11	4	10¾	4	12¾	3	16½
1864	0	8¼	0	9½	0	9¾	0	9½	2	17¼	3	12¾	4	4¾	4	3½	9	11½	9	5	9	15	8	17¼
1868[1]																								
1872	3	0	2	2⅞	2	16½	1	17¼	7	16⅞	9	8	9	4⅞	10	10	18	6¼	18	15⅝	18	4¾	18	9
1876	1	16¾	1	2¼	1	17⅜	1	6	10	10¼	10	16¾	11	4¾	12	13¼	17	4½	20	11¼	20	18	21	2¼
1880	1	16½	0	16¼	2	2¼	1	4	11	16½	10	11¼	12	11⅝	11	14¾	24	6¼	24	2¾	24	5¼	24	5
1884	1	5¼	0	8¼	1	7¼	0	17	8	18¼	9	13½	9	11¼	11	9	17	13½	17	10	18	2½	17	4½
1888	1	2	0	4	1	10½	0	11¼	7	18	11	8½	9	2	13	12¼	23	9	25	18½	22	18¾	22	18
Average: 8 courses, 1852 to 1880	1	9¼	0	19⅝	1	6⅞	0	17¾	7	4¼	6	18⅜	8	1¼	8	3⅛	14	3½	14	10½	14	12	14	7¾
Average: 2 courses, 1884 and 1888	1	3¾	0	6⅛	1	8⅞	0	14⅛	8	8¼	10	11⅛	9	6⅝	12	10⅝	20	11¼	21	14¼	20	10⅝	20	1⅜

[1] Crop failed.

The first point to notice in the results is that, under each condition as to manuring, there is very great variation in the amount of produce from year to year, according to the seasons. Thus, in 1868, the crop entirely failed on all the plats, although seed was sown twice. Again, whilst the complex manure containing nitrogen yielded more than 22 tons of roots in 1880, the same manure gave little more than 4 tons in 1860; the average yield over the eight courses being about 13¼ tons. Against this, the average by superphosphate alone ranged from about 6½ to about 7½ tons, whilst without manure there was an average of only about 1 ton.

Referring to this last result, it is particularly to be observed that this assumed restorative crop yields practically no produce at all when grown without manure.

The plat with superphosphate alone gives very much more than that without manure, but still very much less than an average agricultural crop. The increase, such as it was, was largely due to the greatly increased development of feeding root within the surface soil, under the influence of the phosphatic manure; and the necessary nitrogen, beyond the small amount of combined nitrogen annually coming down in rain and the minor aqueous deposits from the atmosphere, has doubtless been gathered, under the influence of the increased root development, from the previous accumulations within the soil itself. There is, in fact, perhaps no agricultural practice by which what is termed the condition of land, that is the readily available fertility due to recent accumulation, can be so rapidly exhausted as by growing turnips on it by superphosphate alone, provided, of course, that the seasons are favorable.

Compared with the produce with superphosphate alone, the mixed manure (supplying besides superphosphate, not only salts of potash, soda, and magnesia, but a liberal amount of nitrogen) yielded, on the average of the eight courses, nearly twice as much, or between 13 and 14 tons of roots; though, as already pointed out, it yielded in some seasons over 20 tons per acre. There can be no doubt that, the necessary mineral constituents being available, there was a large increase of produce due to the supply of nitrogen in the manure.

The figures in the middle division of the table show that the produce of leaf as well as that of roots was increased by superphosphate, and that it was still further increased by the mixed manure containing nitrogen. The next point is to consider the effects of the other conditions besides those of different manure supply; that is, the removal of the root crop, or the feeding or the spreading of it upon the land; also whether, in the third year of each course, a leguminous crop was grown or the land was fallowed.

It is seen that without manure, whether clover or beans were grown, or the land were fallowed, there was even rather less average produce over the eight years where the roots were fed on the land than where

they were carted off; but with such very small crops the differences are immaterial, if not accidental.

On the superphospate plats where the produce was much higher, and where there would therefore be more loss to the land by removal, the crops were materially better on the fed portions of the plats.

On the mixed manure plats, on the other hand, with nearly twice as much produce as with superphosphate alone, there would be still greater difference between the condition of the land where the roots were carted off and where they were fed on; but there was very little difference in the average produce of the root crop.

It will be seen further on, that the higher condition of the land where the more highly manured roots were fed upon it, had a very marked effect on the succeeding cereal crops; and especially on the immediately succeeding barley. This was the case on both the superphosphate and the mixed manure plats.

The difference of effect on the average produce of the root crop by fallowing, or by growing beans or clover in the third year of each course is, in the comparable cases, practically immaterial under each of the three different conditions as to manuring.

Before passing from Table 56 it is to be observed that there was higher average produce over the tenth and eleventh courses with superphosphate and potash, soda, and magnesia, than over the preceding eight courses with superphosphate alone. But as there was also increase in a greater degree with the mixed mineral and nitrogenous manure, over the two than over the eight years, it is obvious that the character of the seasons had a good deal to do with the result. It is noticeable, however, that on the plats with potash, soda, and magnesia, as well as superphosphate, in the two courses, there was a higher produce of roots on the plats where beans or clover was grown than on those that were fallowed, a result doubtless due to the increased growth of the leguminous crop under the influence of the potash manuring and accumulation of nitrogen in the soil thereby.

It may further be observed (though not shown in the table) that in 1892, that is—the first year of the twelfth course—the produce of the manured plats was generally higher than in either of the two preceding courses. The accompanying figures (p. 181) represent selected typical Swedish turnip plants, grown in 1892, without manure, with the mixed mineral manure alone, and with the mixed mineral and nitrogenous manure. Each plant was fixed upon a scaled background and so photographed, and the figures as given are about one-twentieth natural size, and strictly comparable. The quantities of produce recorded show that without manure it was less, but that by each of the two descriptions of manure it was considerably more than the average of the preceding courses; and both the reversion to the uncultivated condition without manure, and the increased growth under the influence of each of the manures, are strikingly illustrated, both by the figures and by

the amounts of produce given. Indeed, the results conclusively show how artificial a product is the cultivated root crop, and how dependent it is for its successful growth on an abundant supply of available food —nitrogenous as well as mineral—within the soil.

[Unmanured continuously; crop of roots, 1892, 8¼ cwts. per acre.]

[Mineral manure commencing each course; crop of roots, 1892, 11 tons 6¼ cwts. per acre.]

[Mineral and nitrogenous manure commencing each course; crop of roots, 1892, 24 tons 18 cwts. per acre.]

FIG. 6.—Swedish turnips, grown in 4-course rotation, in Agdell field; forty-fifth year, 1892; first crop, twelfth course.

THE BARLEY CROPS.

Table 57 gives the produce of barley, the second crop of the course, and therefore always succeeding the roots, in each of the eleven years in which it was grown, in precisely the same form as that of the Swedish turnips recorded in Table 56; the upper division giving the grain per acre, the middle division the straw, and the lower one the total produce, grain and straw together.

As in the case of the root crops, so in that of the barley; the produce in the first course is excluded from the calculation of the averages to which reference will chiefly be made. Indeed, the results of the first year of barley confirm the conclusion that the land was in somewhat high condition, due to recent accumulations. The produce of the tenth and eleventh courses is also excluded from the averages on account of the change of manure on the superphosphate plat for the tenth and succeeding courses.

TABLE 57.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eleven courses, forty-four years, 1848–1891).*

2. BARLEY.

Years.	Unmanured.				Courses 1 to 9, superphosphate only; courses 10 and 11, mixed mineral manure.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
DRESSED GRAIN.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1849	33¾	44⅞	44⅞	48⅛	29⅛	29⅞	41	42¾	37	28⅞	44⅛	42⅞
1853	32⅛	34⅜	33	28⅞	32	28⅝	39⅞	38	37⅞	38¼	37⅛	35⅜
1857	43¾	48½	44¼	40⅛	30¾	28½	48¾	52⅝	47½	48	66⅝	63⅛
1861	35½	38⅝	33	29⅝	32⅜	30⅝	40⅜	42½	60⅞	60⅝	57¾	54⅜
1865	34½	39	35⅛	27¾	31¼	33¼	39⅛	41¼	44⅝	47½	46⅝	43⅜
1869	21⅜	24⅝	21	25⅝	25½	28¾	30⅛	33½	39¾	42⅞	38⅜	42¼
1873	20¾	23½	20⅞	22⅞	22⅛	20¾	27	29⅜	31½	31¾	47	45⅛
1877	23	23½	22½	23⅝	21	24¼	31⅜	38⅜	30¾	34¾	44⅝	49⅛
1881	29⅛	26¾	31⅜	25⅞	24¼	24½	28⅛	28¾	33⅜	35⅜	47⅞	50¼
1885	15½	12⅛	22¾	16	12⅞	19⅞	17⅛	32½	19	34¾	32¼	44¾
1889	15½	11	16⅞	12⅝	15⅛	21¾	19¼	29¾	20	26⅝	23½	25½
Average: 8 courses, 1853 to 1881	30	32⅜	30⅛	28	27⅜	27⅜	35⅝	38	40¾	42⅜	48⅜	47⅞
Average: 2 courses, 1885 and 1889	15½	11⅝	19⅞	14⅜	14	20⅞	18¼	31⅛	19½	30¾	27⅞	35⅛
STRAW.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1849	2,200	2,983	3,139	3,225	1,870	2,111	3,209	3,327	2.842	2,088	3,709	3,646
1853	2,187	2,430	2,210	2.077	2.003	1,873	2.729	2,756	2,595	2,604	3.323	2,981
1857	2,330	2,600	2,430	2 312	1,545	1,475	2,595	2.780	2,400	2,435	3.570	3,405
1861	2,190	2,522	2,018	1,970	1,954	2,000	2,475	2.553	3,920	3,940	4.175	3,940
1865	1,828	2,154	1,809	1,460	1,509	1,615	2,043	2,244	2,398	2.595	3,274	2.958
1869	1,628	1,948	1,648	1,944	1,873	2,025	2,265	2,401	3,064	3,309	3,244	3,229
1873	1,374	1,343	1,311	1,495	1,370	1,565	1,611	1,841	1,626	1,723	2,796	2,456
1877	1,244	1,291	1,275	1,341	1,054	1,174	1.706	1,994	1,625	1,918	2.646	3,125
1881	1,556	1,484	1,568	1.468	1,239	1,259	1,500	1,430	1,755	1,853	2,993	3,078
1885	1,518	1,270	1,768	1,379	1,043	1,441	1.480	2,358	1.528	2.461	2,778	3,386
1889	953	931	996	865	965	1,221	1,135	1,613	1.231	1,685	1,776	2,030
Average: 8 courses, 1853 to 1881	1,792	1,971	1,784	1,758	1.568	1,623	2,116	2.250	2,423	2,547	3,253	3,147
Average: 2 courses, 1885 and 1889	1,236	1,101	1,382	1,122	1,004	1,331	1,308	1,986	1,380	2,073	2,277	2,708
TOTAL PRODUCE.												
1849	4,149	5,656	5,785	6,046	3,575	3,841	5.708	5,885	5,026	3,794	6,344	6,206
1853	4,046	4,464	4.161	3,817	3,876	3,560	5,110	5,058	4,849	4.873	5,672	5,190
1857	4,777	5,337	4.912	4,558	3,272	3.076	5,326	5,741	5.091	5,168	7.261	6.930
1861	4,248	4,718	3,871	3,635	3,807	3.775	4.803	4,982	7,419	7.391	7,554	7,148
1865	3,659	4,182	3.695	2,961	3,170	3,394	4,122	4,457	4.799	5,148	5,753	5,308
1869	2,881	3,358	2,843	3.387	3.328	3,686	3,999	4,313	5.414	5,800	5.491	5,701
1873	2,596	2,717	2,536	2,844	2,713	2,875	3,209	3,575	3.412	3,573	5.478	5,018
1877	2,602	2,623	2,609	2.673	2,304	2,558	3,530	4,157	3.406	3,890	5.217	5,963
1881	3,170	2,922	3,297	2,929	2,576	2,641	3,083	3.057	3,651	3,857	5,720	5,964
1885	2,402	1,960	3,056	2.235	1.833	2,538	2,576	4.193	2,643	4,426	4,624	5,946
1889	1,789	1,510	1,898	1,530	1.775	2,402	2,248	3,250	2,362	3.134	3,045	3,409
Average: 8 courses, 1853 to 1881	3,497	3,790	3,491	3,350	3,131	3,196	4,148	4,417	4,755	4,962	6.018	5,903
Average: 2 courses, 1885 and 1889	2,096	1,735	2,477	1,883	1,804	2,47[illegible]	2,412	3,722	2,503	3,780	3,835	4,678

Referring, however, first to the results of each of the eleven years, it is seen that under each condition of manuring or other treatment there is very great variation in the amount of produce from year to year due

to variations in the characters of the seasons. Thus, without manure, the average produce over the eight courses was about 30 bushels per acre, while in 1857 it was in each case more than 40 bushels, and in some considerably more; but in 1869 and in 1873 it was not much over 20 bushels, and in the last two courses considerably less than 20. A glance down the columns recording the produce on the manured plats will show that in their case also there was a wide range in amount above and below the averages, according to season.

Referring now to the average produce of the eight courses (second to ninth), the first point to notice is that while the assumed restorative crop—the roots—gave practically no produce at all without manure, the barley gave, on land unmanured for so many years, an average of rather over 30 bushels per acre. The truth is that the cultivation for the preceding roots kept the land clean, and as there was practically no produce of roots, the soil was in point of fact left almost fallow for the barley during the winter preceding the roots, during the root-crop period itself, and during the succeeding winter before the sowing of the barley. There was, therefore, very good preparation for the barley. It will be seen further on that when grown continuously without manure both wheat and barley yield more in proportion to their respective averages under ordinary cultivation than does either of the fallow crops—the roots or the leguminous crops. Yet, the produce of barley in rotation, without manure, was much in excess of that when it is grown continuously, the explanation doubtless being, as above referred to, that the crop had been grown after well-cultivated bare fallow.

Next it is to be observed that, there having been practically no crop of roots without manure, there was no material difference between the yield of the succeeding barley where the roots were carted off or where they were fed on the land.

Turning now to the produce on the four plats with superphosphate alone, it is seen that while the average yield of barley on the two portions from which the roots had been carted off was under 28 bushels, that on the portions where they had been fed on the land was in one case more than 35½ and in the other 38 bushels. The effect, on the one hand, of the removal of the larger crop of roots, and on the other of the retention on the land of the greater part of its constituents, is thus very evident. It is further to be remarked that the produce of barley where the roots grown by superphosphate had been removed from the land was even less than on the two corresponding portions of the unmanured plat. Thus there is confirmation of the supposition that the higher crop of barley without manure was due to the previous preparation and conservation of constituents by fallow, and that the lower produce on the superphosphate plat, where the roots had been removed, was largely due to so much greater exhaustion, especially of the available nitrogen of the surface soil.

Next it is seen that, on the plats where the mixed manure containing nitrogen had been applied for the preceding turnips, the produce of barley was on a much higher level; and it was much higher on the portions where the turnips had been fed on the land than on those from which they had been removed.

It may be observed that the produce, even on the plats with superphosphate alone, was, where the roots had been fed on the land, about the average of the country at large under ordinary rotation, namely, from 36 to 38 bushels; while on the full-manured plat the produce was much more than this, namely, in one case $40\frac{3}{4}$ and in the other $42\frac{3}{8}$ bushels, where the roots had been removed; and where they had been fed on the land, in one case $48\frac{3}{8}$ and in the other $47\frac{7}{8}$ bushels.

Thus, then, the effect on the succeeding barley of the full mineral and nitrogenous manure applied for the preceding turnips is very obvious, while the effect, on the one hand, of the removal of the root crop, and on the other of the retention on the land of most of its constituents, is also very marked. The experimental results relating to the second crop of the course—the barley—so far fully confirm, therefore, the explanations which have been given of the beneficial effects of root crops grown under the ordinary conditions of manuring on the succeeding cereal grown in alternation with them.

Examination of the results relating to the quantities of straw and of total produce (grain and straw together), as given in the middle and lower divisions of the table, will show that they fully bear out the general conclusions that have been drawn from a consideration of the produce of the grain alone.

THE LEGUMINOUS CROPS (OR FALLOW).

Table 58 gives for the third element of the typical four-course rotation—the leguminous crops—the results obtained in each of the eleven years of the forty-four in which they were grown in exactly the same form as those previously recorded for the turnips and for the barley, But as in some of the years clover, and in others beans were grown, the averages are here taken, not for the eight and for the two courses. as with the other crops, but, respectively, for the four years of the eleven in which clover was grown and for the seven in which beans were grown.

TABLE 58.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eleven courses, forty-four years, 1848–1891.)*

3. CLOVER (OR BEANS) OR FALLOW.

[Beans; dressed corn, 1854, 1858, 1862, 1866, 1870, 1878, and 1890. (Clover, 1850, 1874, 1882, and 1886).]

Years.	Unmanured.				Courses 1 to 9, superphosphate only; courses 10 and 11, mixed mineral manure.				Mixed mineral and nitrogenous manure.			
	Roots earted.		Roots fed.		Roots earted.		Roots fed.		Roots earted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1850	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1854	......	$5\frac{1}{8}$	......	$5\frac{1}{2}$	......	$5\frac{7}{8}$	......	$10\frac{5}{8}$	......	$9\frac{7}{8}$	......	$13\frac{3}{8}$
1858	......	$6\frac{1}{4}$	......	$5\frac{1}{8}$	......	$6\frac{1}{2}$	......	$8\frac{5}{8}$	......	$12\frac{3}{8}$	......	$14\frac{3}{4}$
1862	......	29	......	27	......	$29\frac{3}{4}$	......	30	......	$43\frac{3}{8}$	......	$41\frac{1}{8}$
1866	......	$10\frac{1}{4}$	......	$8\frac{3}{4}$	......	$7\frac{3}{8}$	......	10	......	$20\frac{3}{8}$	......	$24\frac{3}{4}$
1870	......	$13\frac{3}{8}$	......	$17\frac{7}{8}$	......	$15\frac{5}{8}$	......	$15\frac{3}{8}$	......	$24\frac{5}{8}$	......	$26\frac{5}{8}$
1874	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1878	......	$8\frac{3}{4}$	......	$7\frac{3}{3}$	......	$7\frac{3}{4}$	......	$13\frac{7}{8}$	......	$20\frac{1}{4}$	......	$26\frac{5}{8}$
1882	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1886	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1890	......	7	......	$8\frac{1}{4}$	......	$24\frac{5}{8}$	......	24	......	$15\frac{1}{4}$	......	$16\frac{3}{4}$
Average 7 courses beans	......	$11\frac{3}{8}$	......	$11\frac{3}{8}$	......	$13\frac{7}{8}$	......	$16\frac{1}{8}$	......	$20\frac{7}{8}$	......	$23\frac{3}{8}$

[Beans; straw, 1854, 1858, 1862, 1866, 1870, 1878, and 1890. (Clover, 1850, 1874, 1882, and 1886).]

	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1850	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1854	......	1,055	......	953	......	1,103	......	1,378	......	1,355	......	1,605
1858	......	1,100	......	965	......	1,155	......	1,320	......	1,520	......	1,760
1862	......	1,840	......	1,845	......	2,150	......	2,155	......	3,280	......	2,945
1866	......	1,013	......	905	......	978	......	1,835	......	1,990	......	2,155
1870	......	738	......	710	......	768	......	878	......	1,056	......	1,008
1874	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1878	......	740	......	775	......	1,045	......	1,350	......	1,655	......	1,880
1882	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1886	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover	......	Clover
1890	......	603	......	633	......	1,764	......	1,630	......	1,102	......	1,059
Average 7 courses beans	......	1,013	......	969	......	1,280	......	1,507	......	1,708	......	1,773

[Clover (as hay), 1850, 1874, 1882, and 1886. Beans (corn and straw), 1854, 1858, 1862, 1866, 1870, 1878, and 1890.]

1850	(6,440)	(5,920)	(7,027)	(5,413)	(6,799)	(6,329)	(6,739)	(5,580)	(7,697)	(6,921)	(7,275)	(6,753)
1854	......	1,445	......	1,367	......	1,534	......	2,124	......	2,065	......	2,544
1858	......	1,515	......	1,307	......	1,605	......	1,895	......	2,357	......	2,754
1862	......	3,661	......	3,546	......	4,040	......	4,027	......	5,990	......	5,520
1866	......	1,689	......	1,485	......	1,463	......	2,481	......	3,343	......	3,782
1870	......	1,591	......	1,854	......	1,778	......	1,867	......	2,664	......	2,746
1874	......	(2,838)	......	(2,498)	......	(5,093)	......	(6,186)	......	(7,904)	......	(7,708)
1878	......	1,301	......	1,255	......	1,557	......	2,241	......	2,963	......	3,617
1882	......	(2,935)	......	(2,492)	......	(6,700)	......	(7,927)	......	(8,882)	......	(9,374)
1886	......	(1,285)	......	(1,305)	......	(4,925)	......	(4,695)	......	(3,255)	......	(3,645)
1890	......	1,079	......	1,197	......	3,441	......	3,269	......	2,145	......	2,195
Average 7 courses beans	......	1,754	......	1,716	......	2,203	......	2,558	......	3,075	......	3,308
Average 4 courses clover	......	3,245	......	2,927	......	5,762	......	6,097	......	6,741	......	6,870

A glance at the table brings to view some of the difficulties connected with the growth of these crops. Thus, although the scheme of the four-course rotation supposes the growth of red clover as the third crop of each course, that is once in four years, it has in fact only been grown four times in the forty-four years, namely, in the first, seventh, ninth, and tenth courses; and when it failed beans were grown instead. It is, indeed, a matter of general knowledge and experience, that it is only on a few descriptions of soil that clover can be grown so frequently as every fourth year; and in many cases it is not attempted to grow it more than once in eight years. The difficulty of growing red clover or beans frequently on ordinary arable land was fully illustrated in the section on the growth of leguminous crops. On the other hand, it was shown that red clover might be grown for many years in succession on rich garden soil; and further, that on ordinary arable land where clover had entirely failed, some other Leguminosæ, having more extended root-range, or more powerful root habit, grew luxuriantly and yielded large crops containing large amounts of nitrogen, for a number of years in succession. Lastly, in another field, where beans had frequently failed, red clover was afterwards sown and gave unusually large crops.

Referring to the results in Table 58 it is seen that when clover was grown in 1850, that is in the first course, and when it had not been grown on the same land for many years, large crops were obtained on all the plats, though the larger where the mixed manure including potash (and also nitrogen) had been applied for the root crop three years previously. For the second, third, and fourth courses, clover was sown with the preceding barley, but in all three it failed in the winter, and beans were grown instead; that is, in 1854, 1858, and 1862. After these repeated failures, clover was not sown for the fifth and sixth courses, but beans were taken instead in 1866 and in 1870. In the seventh course, clover was sown again with the barley, and gave three cuttings in 1874; that is, twenty-four years since the last good crop. Without manure the produce was, however, not much more than 1 ton per acre; with superphosphate it was much more, and with the mixed manure, including potash, much more still—corresponding to about 3½ tons of clover hay. For the eighth course clover was not sown, but beans were taken in 1878. For the ninth and tenth courses, however, clover was again sown, yielding in the ninth (1882) even more than in 1874, but in the tenth (1886) very much smaller crops; though more with mineral manure alone, now including potash, than with the mixed manure containing nitrogen also. Lastly, for the eleventh course clover was again sown with the barley, but failed, and in 1890 beans were grown instead; the crops, as in the case of the clover in the tenth course, being greater with mineral manure alone (now including potash), than with the mixed manure containing nitrogen also.

Thus, in only four out of the eleven years in which clover should have been grown, was any crop obtained, and beans had to be taken in the

other seven. The produce of clover is given in the lower division of the table, side by side with the total produce (corn and straw) of the beans, and the figures are entered in parentheses.

Briefly to summarize the results given in the table, it may be stated that the average produce of clover, reckoned as hay, was, without manure, rather over 3,000 pounds; with the superphosphate (in the last year, with potash, soda, and magnesia also) nearly 6,000 pounds; and with the mineral and nitrogenous manures together for each course, about 6,800 pounds. With the mineral manure alone, therefore, there was about twice as much, and with the mineral and nitrogenous manures together, considerably more than twice as much as without manure. Compared with these amounts of clover reckoned as hay, the seven bean crops (corn and straw together) gave an average of about 1,700 pounds without manure, of nearly 2,400 pounds with mineral manure alone, and about 3,200 pounds with the mineral and nitrogenous manures together.

Not only, therefore, was the average produce of the bean-crop very much less than that of the clover, but in point of fact it was only in one year, 1862, that anything like a really good crop of beans was obtained. It may be added, though the point will be further illustrated presently, that the crops of the four years of clover contained, even without manure, about as much nitrogen as, and with each of the two manures considerably more, than those of the seven years of beans. In fact, the average produce of the bean crop and of nitrogen in it, was very much less than in the case of the clover. Nevertheless, even the average yield of nitrogen was much more in the beans than in either of the cereals with which they were grown in alternation. Thus, without manure, the four clover crops gave an average of 60.2 pounds of nitrogen per acre, and the seven bean crops 34.9 pounds, but over the eleven courses the barley gave an average of only 28 pounds, and the wheat of only 31.7 pounds. With mineral manure alone the average yield of nitrogen was, in the clover 119.2 pounds, in the beans 49.2 pounds, in the barley only 27.7 pounds, and in the wheat only 39.3 pounds. Lastly, with mineral and nitrogenous manure together, the clover gave an average yield of nitrogen of 134.6 pounds, the beans of 64.1 pounds, the barley 41.2 pounds, and the wheat 43.5 pounds. There can, indeed, be no doubt that the leguminous crops, and especially the clover growing on land in the same condition and similarly manured, have the power of taking up much more nitrogen over a given area from some source than the cereals with which they are interpolated, and that the beneficial effects of the growth of such crops in rotation with the cereals are intimately connected with this capability.

Before passing from the results in Table 58 it may be observed that, both with mineral manure alone and with mineral and nitrogenous manure together, there is rather more produce, both of the clover and

of the bean crop, where the roots had been fed upon the land than where they had been carted off; that is, the higher the condition of the land. Thus, then, the effects of the treatment of the first crop of the course—the roots, on the produce of the third or leguminous crop, are clearly shown.

As already referred to, in the second and subsequent courses, when the third year came round each plat was divided, clover or beans being grown on one-half, and the other half left fallow. We have, therefore, the means of comparing the effects on the other crops of the rotation—of fallow on the one hand, which of course removes nothing (though there may be the more loss by drainage), and of growing beans or clover on the other, a characteristic of which is the assimilation, and consequently the removal in the crops, especially of large amounts of nitrogen, but of other constituents also; at the same time, however, leaving in the land more or less of nitrogenous crop-residue. Such a comparison obviously has a special interest, since it is chiefly as a substitute for fallow that the growth of leguminous crops has been introduced into our rotations.

THE WHEAT CROPS.

Table 59 records the results obtained with the fourth element of the rotation—the wheat, exactly in the same form as in the case of the other crops:

TABLE 59.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eleven courses, forty-four years, 1848–1891).*

4. WHEAT.

Years.	Unmanured.				Courses 1 to 9, superphosphate only; courses 10 and 11, mixed mineral manure.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Dressed grain.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1851	30½	28½	31¼	30⅞	31⅜	28	32⅞	32	30⅛	28⅞	27½	31¾
1855	37⅜	35¼	37¼	34¼	38⅞	35¼	37⅝	36⅜	38¼	37⅞	37⅜	40¾
1859	35¾	35¼	35½	30¼	37⅛	34¾	39⅝	37¼	42⅜	39¾	40½	38⅞
1863	45	34⅛	42	30⅛	46	34⅞	49⅛	41⅞	52⅝	46⅛	49	44⅝
1867	27⅛	21	23⅜	15⅛	26⅛	19¾	27⅛	25	22⅜	23¾	19⅞	21¼
1871	14½	20⅝	14½	21⅜	16⅛	23⅞	15⅜	23	17⅜	24	17¼	25½
1875	24⅜	21⅝	24⅛	19⅝	28⅞	28¼	30⅝	31¾	29⅛	31⅞	30	30⅛
1879	10⅛	10⅜	11¾	8⅞	14¾	14⅜	14⅛	15½	12⅜	13	10⅜	14
1883	33½	29⅜	34¼	25¾	38½	36⅛	40½	40	37½	45⅛	39¼	50⅛
1887	34¾	25⅝	33⅛	27¼	41⅝	42¼	40¼	44¾	39⅛	42¼	41	43¼
1891	32	29½	31¼	26⅛	36	42¼	40	50¼	41	44⅜	45¼	42
Average 8 courses, 1855 to 1883	28½	26	27⅞	23¼	30¾	28½	31¾	31⅜	31½	32⅝	30½	33¼
Average 2 courses, 1887 and 1891	33⅜	27½	32⅜	26⅞	38¾	42¼	40⅛	47½	40¼	43⅜	43⅛	42⅝
Straw.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1851	3,273	3,431	3,498	3,760	3,497	3,371	3,834	4,014	3,610	3,552	3,969	4,035
1855	4,295	3,619	4,070	3,351	4,286	3,525	4,492	3,611	4,952	3,942	5,107	4,370
1859	4,315	4,030	4,045	3,355	4,310	3,930	4,720	4,320	5,330	4,610	5,545	4,955
1863	4,563	3,468	4,295	3,008	4,690	3,390	5,051	3,888	5,495	4,698	5,638	4,919
1867	2,654	2,143	2,598	1,524	2,774	1,966	2,989	2,648	2,850	3,003	2,965	1,654
1871	2,075	2,799	1,946	2,655	2,128	3,048	2,240	2,980	2,628	3,440	2,863	3,644
1875	2,833	2,430	2,851	2,353	3,230	3,536	3,525	3,928	3,623	4,685	4,085	4,385
1879	1,493	1,324	1,612	1,219	1,956	1,771	1,843	1,771	1,691	1,658	1,426	2,138
1883	2,994	2,280	3,231	2,060	3,686	3,021	4,110	3,275	3,689	4,024	4,028	4,505
1887	2,505	1,859	2,655	1,844	3,465	3,298	3,489	3,468	3,308	3,423	3,763	3,645
1891	2,941	2,598	2,898	2,318	3,586	3,995	4,103	5,017	4,288	4,575	4,938	4,309
Average 8 courses, 1855 to 1883	3,153	2,762	3,081	2,441	3,383	3,023	3,621	3,303	3,782	3,758	3,950	3,821
Average 2 courses, 1887 and 1891	2,723	2,229	2,777	2,081	3,526	3,647	3,792	4,243	3,798	3,999	4,350	3,977
Total produce.												
1851	5,290	5,389	5,584	5,855	5,617	5,253	6,062	6,176	5,642	5,500	5,801	6,169
1855	6,735	5,859	6,473	5,526	6,756	5,789	6,961	5,921	7,428	6,371	7,499	6,992
1859	6,582	6,262	6,270	5,265	6,671	6,120	7,242	6,689	8,066	7,154	8,136	7,417
1863	7,446	5,621	6,999	4,941	7,626	5,619	8,194	6,562	8,837	7,627	8,747	7,721
1867	4,330	3,473	4,126	2,506	4,420	3,222	4,702	4,242	4,328	4,567	4,180	3,023
1871	3,004	4,092	2,840	3,994	3,133	4,521	3,193	4,404	3,747	4,942	3,925	5,236
1875	4,412	3,784	4,396	3,642	5,065	5,328	5,443	5,954	5,448	6,699	5,942	6,292
1879	2,162	1,987	2,351	1,800	2,905	2,729	2,755	2,781	2,478	2,493	2,100	3,034
1883	5,140	4,175	5,445	3,741	6,208	5,400	6,778	5,901	6,132	6,921	6,536	7,743
1887	4,689	3,483	4,811	3,550	6,103	5,994	6,105	6,332	5,894	6,103	6,410	6,409
1891	4,868	4,371	4,763	3,921	5,742	6,546	6,509	8,034	6,748	7,250	7,610	6,811
Average 8 courses, 1855 to 1883	4,976	4,407	4,863	3,927	5,348	4,841	5,658	5,307	5,808	5,847	5,883	5,932
Average 2 courses, 1887 and 1891	4,779	3,927	4,787	3,736	5,923	6,270	6,307	7,183	6,321	6,677	7,010	6,610

Looking first to the figures relating to the individual years, it is seen that, under each condition of manuring or other treatment, there is an enormous variation in the amount of produce in the different years, according to the seasons. Thus, taking for illustration, the results in the first column under each of the three main conditions as to manuring, that is where the roots were carted from the land, and where in the third year of the course it was left fallow, there was, without manure, only $10\frac{1}{8}$ bushels of wheat in 1879, but 45 bushels in 1863; on the superphosphate plat there was in 1879 only $14\frac{3}{4}$ bushels, and 46 bushels in 1863; and on the mixed manure plat only $12\frac{3}{8}$ bushels in 1879, but $52\frac{5}{8}$ bushels in 1863. Or, comparing the quantities of total produce, corn and straw together, which more directly represent the amounts of growth, we have, on the same plats, without manure 2,162 pounds per acre in 1879, and 7,446 pounds in 1863; on the superphospate plat 2,905 pounds in 1879, and 7,626 pounds in 1863, and lastly, on the mixed manure plat, only 2,478 pounds in 1879, but 8,837 pounds in 1863.

The cases cited are those of the most extreme fluctuations due to season; but a glance at the columns will show that there were very considerable variations in other years, under each condition as to manuring, or other treatment; whilst the amounts of the variations differ more or less under the different soil conditions. It will be obvious, therefore, that if we would fairly compare with one another the effects of the varying conditions, it is important to take the average results of a sufficient number of years to eliminate the influence of the varying seasons. Most of our illustrations will, therefore, be drawn from the average results over the eight years of wheat in the second to the ninth courses; but some reference will also be made to the averages for the tenth and eleventh courses.

Let us first compare the average amounts of produce of grain under the three main conditions as to manuring, excluding, however, those obtained on the portion of the unmanured plat where the roots were fed on the land, and where beans or clover were grown in the third year of each course; as the crops, especially of the barley and of the wheat, were somewhat adversely affected by a dell on one side of the plat, the surface soil being in consequence comparatively shallow. The figures show that on the three portions the produce ranged, without manure, from 26 to $28\frac{1}{2}$ bushels; with superphosphate from $28\frac{1}{2}$ to $31\frac{3}{4}$, and with the mixed manure from $30\frac{1}{2}$ to $33\frac{1}{4}$ bushels. Or, taking the amounts of total produce (grain and straw together), the range of amounts is, without manure, from 4,407 to 4,976 pounds; with superphosphate from 4,841 to 5,658 pounds, and with the mixed manure from 5,808 to 5,932 pounds. There is, therefore, both in grain and in total produce of the fourth crop of the course, an obvious difference, but certainly less than might have been expected, due to the varying conditions as to manuring in the first year, separated from the fourth by the growth and removal of the intermediate crops.

Next comparing the effects on the fourth crop—the wheat, of the removal of the first—the turnips, or the retention of them, or of most of their constituents, on the land, it is seen that without manure, under which condition there were practically no roots grown, the difference of result from removal or otherwise is quite immaterial, and is probably accidental. With superphosphate alone, and more roots grown, the nitrogen of which was doubtless obtained from previous accumulations within the soil, the removal or the retention on the land of the constituents of the turnips should, therefore, more materially affect the condition of the soil for the growth of the succeeding crops. It was shown that the effect was very marked on the barley which immediately succeeded the roots. There was also somewhat less produce, both of clover and of beans, where the roots had been removed; and now, in the case of the fourth crop—the wheat—there is still distinct effect. Thus, taking the fallow portions, there was an average of 30¾ bushels of wheat where the roots had been removed, and 31¾ bushels where they were fed or retained on the land, the corresponding amounts of total produce being 5,348 pounds and 5,658 pounds. Or, taking the produce on the bean and clover portions, there were 28½ bushels of grain where the roots had been removed, and 31⅜ bushels where they had not been removed, the corresponding amounts of total produce being 4,841 pounds and 5,307 pounds. Lastly, with the mixed manure, including nitrogen, the average produce was, on the fallow portions, 31½ bushels after the removal of the roots, but only 30½ where they had not been removed, the amounts of total produce being, however, 5,808 pounds and 5,883 pounds. On the bean or clover portions the results were 32⅝ bushels where the roots were carted, and 33¼ bushels where they were not removed, and the amounts of total produce were 5,847 and 5,932 pounds.

Reference to the average produce of the last two courses, the tenth and eleventh, the wheat years of which were of more than average productiveness, shows in the case of the manured plats more striking difference in the amount of the fourth crop, due to the removal or the retention on the land of the constituents of the first crop—the roots. The roots of those courses were, however, more than average in amount.

The results, both with superphosphate alone and with the mixed manure, afford, therefore, distinct evidence of the effect of the removal or otherwise of the first crop of the course—the turnips—not only on the second and third crops, but on the fourth crop—the wheat also.

The next point is to illustrate the difference of effect on the other crops of the rotation, on the one hand, of the growth and removal of the highly nitrogenous leguminous crops, and on the other of fallowing, which removes nothing; and first, as to the wheat, which we are now specially considering, and which immediately succeeds the leguminous crop or the fallow.

A careful examination of the average results over the eight courses (second to ninth) will show that, both without manure, and with superphosphate alone, that is, under conditions of exhaustion, especially of available nitrogen, the wheat crops were in every case higher after fallow, with its supposed accumulation, than after the leguminous crops, which removed much more nitrogen than the succeeding wheat would require. On the other hand, on the mixed manure plats, where the condition of the land, and especially its nitrogenous condition, was not exhausted, but fairly maintained, there was even rather more average produce of wheat after the removal of the highly nitrogenous leguminous crops than after the accumulations of the fallow.

It is unsafe to form general conclusions from the results of individual years, since the characters of the seasons may have so much influence. But it may be observed that after the heavy crops of clover on the superphosphate plats in 1882, and more where the roots were fed than where they had been removed, the wheat crops of the next year, 1883, which were higher than average, were lower after the leguminous crop than after fallow, whilst on the highly-manured plat they were much the higher after the leguminous crop. In the tenth course, however, after the use of potash as well as superphosphate, there were fair but by no means such heavy crops of clover as in the very favorable season of the preceding course, and there was less where there had then been the larger crop; and in the eleventh course also there was less total produce of beans where the heavier crop of clover had been grown in the ninth course. The result was, that on the average of the last two courses the wheat gave less instead of more total produce after fallow than after the leguminous crops, but more where the roots had been fed than where they had been carted, that is, more where the land was the less exhausted.

The general result is, that where there was not exhaustion, but accumulation due to manure and to increased crop residue, the growth and removal of the leguminous crops, not only gave large amounts of nitrogen in the removed crops whilst the fallow yielded none, but also left more available nitrogen for the succeeding wheat than was rendered available (and remained) from the resources of the soil after the fallow. In other words, not only were the nitrogen and other constituents obtained in the leguminous crops an entire gain compared with the result of fallow, but on the average of years a somewhat larger succeeding wheat crop was obtained as well.

Here, then, is a striking illustration of the advantages of the interpolation of leguminous crops instead of fallow with the cereals in our rotations; and it is seen that the benefit may be the greater if the land be not abnormally exhausted, as was the case on the continuously unmanured, and on the superphosphate plats.

Although there was thus a great difference between the effects, on the one hand, of the growth and removal of a leguminous crop, and on the

other of fallow, so far as the third year of the course is concerned; yet, where the manurial conditions were not defective, there was even more wheat succeeding the leguminous crop than succeeding the fallow. The influence of the conditions of the third year of the course does not, however, seem to extend in any marked degree to the crops succeeding the wheat; that is, to the roots commencing the next course, and to the barley succeeding the roots.

So far as the roots are concerned, the average results over the eight courses show, both without manure and with superphosphate alone, that is, on the most exhausted plats, that the advantage, if any, is more with the fallow than with the leguminous plats, whilst with the full manure there is scarcely any difference of result clearly traceable to the treatment of the land in the third year of the preceding courses. Over the last two courses again, without manure, no benefit accrued to the root crop by the growth of the leguminous crop as compared with fallow. On the superphosphate plats, however, now with potash, soda, and magnesia as well, and doubtless more leguminous produce accordingly, there were more roots on the leguminous than on the fallow plats; but with the full manure there was practically no difference in the produce of roots on the fallow compared with the leguminous crop plats. Obviously, the fact that there was not materially less produce of roots where the leguminous crops had been grown and removed, as compared with where the land had been fallow, is of itself evidence of the beneficial rather than exhausting effect of their growth and removal, so far as the requirements of the succeeding crops are concerned.

Nor is the effect of the growth and removal of a leguminous crop, compared with fallow, very definite on the barley succeeding the manured roots. It is, however, over the eight courses in favor of the growth of the leguminous crops; and, though with very small crops, it is, excepting without manure, much more so over the last two courses.

From the results as a whole it may be concluded, that where the land was the most exhausted, the growth of the leguminous crop was correspondingly limited, and being at the expense of the little accumulation that there was, its removal further exhausted the immediately available supplies; whilst, where the accumulations were greater, the growth was dependent on a more extended root development, and therefore greater range of collection, the luxuriance was much greater, and the surface soil at any rate gained by an increased amount of highly nitrogenous leguminous crop residue. It has further been seen that the effects of the manuring and treatment of the first crop of the course—the turnips, were manifest in the produce of the fourth crop—the wheat, and also that the effects of fallowing, or of growing and removing a highly nitrogenous crop, in the third year, were clearly traceable on the crop of the fourth year, and to some extent, though in a much less degree, on the subsequent crops commencing the next course.

THE AMOUNTS OF PRODUCE GROWN IN ROTATION AND IN THE VARIOUS CROPS GROWN CONTINUOUSLY.

Obviously when considering what are the benefits arising from rotation as distinguished from the growth of the individual crops continuously, it is desirable, as far as practicable, to compare the results of the two methods in regard to their yield per acre of some of the more important constituents of the crops. For the purposes of such a comparison, it will be of interest to illustrate the point by reference specially to the amounts of dry matter, nitrogen, total mineral matter (ash), phosphoric acid, and potash (and in some cases of lime), in the crops grown in rotation, and in those grown continuously under as far as possible parallel conditions as to manuring. Accordingly, so far as results obtained under rotation are concerned, the amounts of each of the above constituents are calculated in the produce per acre of the respective crops in each of the eight courses (second to ninth), under each of the twelve different conditions as to manuring or other treatment, and the average amounts of these per acre per annum are compared with those in the individual crops grown continuously, as a rule, in the same seasons as those in which the rotation crops were obtained, and under the same or nearly parallel conditions as to manuring. The amounts of the constituents removed per acre in the rotation crops are calculated from the results of actual analyses; and in the case of the continuously grown crops the amounts of dry matter and ash, and sometimes those of nitrogen, are also calculated from direct determinations; but generally the nitrogen, and always the phosphoric acid, potash, and lime are calculated from the percentage composition of the rotation crops grown under parallel conditions as to manuring. It may be stated that, for the purposes of the illustrations given, the results of 60 complete analyses of the ashes of representative samples of the rotation crops, and of 8 of the ashes of the bean plant taken at different stages of its growth, have thus contributed; and it may be added, that the ash analyses were executed by R. Richter, formerly in the Rothamsted laboratory, but now, for some years, of Charlottenburg, Berlin.

THE AMOUNTS OF DRY MATTER PRODUCED IN THE ROTATION AND IN THE CONTINUOUS CROPS.

Table 60 shows the average annual amount of dry matter produced per acre, in each of the four crops—roots, barley, leguminous crop, and wheat—grown in rotation and continuously as above described. It shows the amounts, separately in the roots, leaves, and total produce of the turnips; in the grain, straw, and total produce of the barley and of the wheat; in the corn, straw, and total produce of the beans; and in the clover. It will be seen that the arrangement and headings of the columns are exactly the same as in the tables of produce already considered; and that, for each description of crop, or part of the crop,

the first line shows the amounts obtained under rotation, the second those in the crop grown continuously, and the third the difference between the two.

TABLE 60.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eight courses, thirty-two years, 1852–1883).*

[Average amounts of dry matter per acre in rotation compared with those in crops grown continuously.]

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Swedish turnips.												
Roots:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	359	228	323	205	1,724	1,631	1,918	1,901	3,081	3,128	3,107	3,069
Continuous [1]	236	236	236	236	945	945	945	945	1,876	1,876	1,876	1,876
Rotation + or — continuous	123	—8	87	—31	779	686	973	956	1,205	1,252	1,231	1,193
Leaves:												
Rotation	56	49	52	45	161	176	179	200	310	355	333	354
Continuous [1]	49	49	49	49	142	142	142	142	345	345	345	345
Rotation + or — continuous	7	0	3	—4	19	34	37	58	—35	10	—12	9
Total:												
Rotation	415	277	375	[2]250	1,885	1,807	2,097	2,101	3,391	3,483	3,440	3,423
Continuous [1]	285	285	285	285	1,087	1,087	1,087	1,087	2,221	2,221	2,221	2,221
Rotation + or — continuous	130	—8	90	—35	798	720	1,010	1,014	1,170	1,262	1,219	1,202
Barley.												
Grain:												
Rotation	1,396	1,489	1,399	1,367	1,284	1,294	1,665	1,780	1,917	1,987	2,262	2,273
Continuous	875	875	875	875	1,128	1,128	1,128	1,128	2,298	2,298	2,298	2,298
Rotation + or — continuous	521	614	524	432	156	166	537	652	—381	—311	—36	—25
Straw:												
Rotation	1,493	1,647	1,486	1,459	1,307	1,355	1,765	1,879	2,029	2,129	2,701	2,613
Continuous	947	947	947	947	1,052	1,052	1,052	1,052	2,489	2,489	2,489	2,489
Rotation + or — continuous	546	700	539	512	255	303	713	827	—460	—360	212	124
Total:												
Rotation	2,889	3,136	2,885	[2]2,766	2,591	2,649	3,430	3,659	3,946	4,116	4,963	4,886
Continuous	1,822	1,822	1,822	1,822	2,180	2,180	2,180	2,180	4,787	4,787	4,787	4,787
Rotation + or — continuous	1,067	1,314	1,063	944	411	469	1,250	1,479	—841	—671	176	99
Beans (6 courses), clover (2 courses), or fallow.												
Corn:												
Rotation	......	631	......	625	......	640	......	769	......	1,147	......	1,292
Continuous	......	234	......	234	......	265	......	265	......	581	......	581
Rotation + or — continuous	......	397	......	391	......	375	......	504	......	566	......	711
Straw:												
Rotation	......	879	......	835	......	978	......	1,213	......	1,487	......	1,540
Continuous	......	422	......	422	......	524	......	524	......	799	......	799
Rotation + or — continuous	......	457	......	413	......	454	......	689	......	688	......	741

[1] Average nineteen years, 1849–1852, and 1856–1870. [2] Probably crop too low owing to a dell.

TABLE 60.—*Experiments on the rotation of roots, barley, clover, etc.*—Continued.

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Beans (6 courses), etc.—Continued.												
Total:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	......	1,510	......	1,460	......	1,618	......	1,982	......	2,634	......	2,832
Continuous	......	656	......	656	......	789	......	789	......	1,380	......	1,380
Rotation + or − continuous	......	854	......	804	......	829	......	1,193	......	1,254	......	1,452
Clover:												
Rotation	......	2,309	......	[1]1,996	......	4,717	......	5,645	......	6,714	......	6,833
Continuous	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)	......	-(?)
Average of 8 courses, beans and clover	......	1,710	......	[1]1,594	......	2,393	......	2,897	......	3,654	......	3,832
Wheat.												
Grain:												
Rotation	1,516	1,368	1,483	1,235	1,636	1,514	1,702	1,663	1,685	1,740	1,599	1.752
Continuous	647	647	647	647	766	766	766	766	1,238	1,238	1,238	1,238
Rotation + or − continuous	869	721	836	588	870	748	936	902	447	502	361	514
Straw:												
Rotation	2,636	2,296	2,573	2.036	2,844	2,513	3,021	2,767	3,158	3,137	3,273	3,186
Continuous	1,082	1,082	1,082	1,082	1,204	1,204	1,204	1,204	2,142	2,142	2,142	2,142
Rotation + or − continuous	1,554	1,214	1,491	954	1,640	1,309	1,817	1,563	1,016	995	1,131	1,044
Total:												
Rotation	4,152	3,664	4,056	[1]3,271	4,480	4,027	4,723	4,435	4.843	4,877	4,872	4,938
Continuous	1,729	1,729	1,729	1,729	1,970	1,970	1,970	1,970	3.380	3,380	3,380	3,380
Rotation + or − continuous	2,423	1,935	2,327	1,542	2,510	2,057	2,753	2.465	1,463	1,497	1,492	1,558

[1] Probably crop too low owing to a dell.

THE DRY MATTER IN THE TURNIP CROPS.

Referring first to the upper division of Table 60 relating to the Swedish turnips, it should be stated that results for the crops grown continuously are not available for the same eight years as those grown in rotation; but for each of the three conditions as to manuring the average for nineteen years of growth is taken. So far as manuring is concerned, the unmanured and the superphosphate conditions were the same for the rotation and for the continuous crops. But, in the case of the mixed manure, the rotation plats received a larger amount of nitrogen for the roots, in fact enough to carry the four crops of the course. The continuous plat, on the other hand, received a less amount each year, but, unlike the rotation plats, with no intermediate crops to use up any available residue from the previous application.

The figures show that without manure the difference in the amounts of dry matter produced in rotation and in continuous growth are imma-

terial. The utter failure in both cases without manure is confirmatory of the absolute dependence of this valuable rotation crop on supplies within the soil itself, either from accumulations or from direct manuring.

The less produce of the continuous than of the rotation crops with superphosphate is also quite consistent with the supposition that, under such conditions, the crop greatly exhausts the available nitrogen of the soil, and especially of the surface soil.

With the mixed mineral and nitrogenous manure again there is also considerably less production of dry substance when the crop is grown continuously than when it is grown in rotation. The result is, however, due partly to the larger amount of nitrogen directly supplied by manure to the rotation crops, as above referred to, but partly to the fact that when the same description of root crop, with the same character and range of roots, is grown year after year on the same land, the surface soil becomes close, and a somewhat impervious pan is formed below; conditions which are very unfavorable for a crop which preeminently requires a good tilth for great development of fibrous root within the soil. The results with the mixed manure are, of course, the most comparable with those of ordinary practice; and it is clear that, however explained, much more produce is obtained under rotation than with continuous growth. It need only further be remarked that, of the total dry matter produced, there is many times as much in the edible root as in the leaf which almost wholly remains only for manure again.

THE DRY MATTER IN THE BARLEY CROPS.

The second division of Table 60 (p. 195) compares the amounts of dry matter yielded in barley grown respectively in rotation and continuously—that is, year after year on the same land. The results for the continuously grown crops relate to the average produce of the same eight seasons as those in which the rotation crops were obtained. The unmanured and the superphosphate conditions were also quite parallel in the two series of experiments. In the case of the mixed manure results it should be borne in mind that in the rotation experiments a quantity of manure was applied for the preceding crop, the turnips, which is supposed to carry the whole of the crops of the four-years' course; whilst, in the continuous experiments, the quantity of nitrogen, for example, which is applied each year for the immediate crop, amounts to rather more than one-fourth of that applied for four years in the rotation experiments.

The figures show that, without manure, there was much less dry matter in grain, straw, and total produce, in the crops grown continuously than in those grown in rotation; in fact, in the total produce only about three-fifths as much. The much higher amount under rotation is quite consistent with the explanation that in the rotation experiments without manure, the roots having failed, the barley crop had, in point of fact, the benefit of the preparation which bare fallow is known to confer.

With superphosphate alone, the continuously grown barley crops yielded more dry matter in grain, straw, and in total produce than those without manure, the excess being largely due to increased capability of utilizing the available nitrogen of the surface soil, under the influence of the phosphatic manure. Both sets of the superphosphate rotation crops yielded more dry matter than the continuous ones, the excess being, however, much less where the rotation roots had been removed than where they had been consumed or spread upon the land. The effect of the growth and accumulation by the previous root crop, and of the more or less available manurial residue left under the different conditions, as compared with the result when the barley is grown year after year on the same land, is thus very evident.

As already said, the amount of nitrogen annually applied on the mixed manure plat was, for the continuous crops, somewhat more than one-fourth of that applied for the preceding root crops, in the case of the rotation plats. Under these circumstances, the amounts of dry matter in grain, straw, and total produce were considerably less in the barley grown in rotation where the roots and leaves of the turnips had been removed, than in that grown continuously; but where, in the case of the rotation barley, the root crops had been consumed or spread upon the land, the average yield of dry matter per acre was much more nearly identical under rotation and under continuous cropping; though, upon the whole, it was more under rotation. The effects on the second crop of the course of the manurial and other treatment of the first crop are here then further illustrated. Lastly, it is to be observed that a larger proportion of the total dry matter of the crop is, on the average, accumulated in the straw which is generally retained on the farm, than in the grain, which is, as a rule, exported from it.

Thus, both the actual and the comparative results clearly show that the successful growth of the barley was directly dependent on the supplies within the soil, and that the object may be gained either in a properly manured rotation, or by the direct application of suitable manures, including a liberal supply of nitrogen, for the immediate crop. Having regard to the general economy of the farm, the former plan is, as a rule, the most advantageous, though, owing to the success with which the crop can be grown by direct artificial manures, such manures are often used as supplements; or sometimes a barley crop is taken after another cereal, by the aid of artificial manures alone.

THE DRY MATTER IN THE LEGUMINOUS CROPS.

The third division of Table 60 (p. 195) shows the average amounts of dry matter per acre per annum in the corn, straw, and total produce of the six crops of beans grown in rotation in the eight years; also the average amounts in the same six years, when the crop was grown continuously in another field. Below the bean results are given the average amounts per acre per annum in the clover grown in rotation

in the remaining two of the eight years, and there are also given the average amounts over the eight years, in the six crops of beans, and two of clover. It will be seen, however, that there is no entry in the line for continuous crops of clover, for the simple reason that, as has been shown in Section III, it was found impossible to grow clover year after year on ordinary arable land.

The figures show that, meager as was the average produce of dry matter in the crops of beans, even when grown in rotation, they were much less still when grown continuously. This was the case, whether we look to the amounts in the corn, the straw, or the total produce. Indeed, the lines of total produce show that the average amounts in the continuously grown crops were, under each condition of manuring or other treatment, less than half as much as those grown in rotation. In both cases there was somewhat more with superphosphate than without manure, and more still with the mixed manure, including both potash and nitrogen, but even under these conditions, and in rotation, the produce was very small.

Under each condition as to manuring, the produce of dry matter in the clover grown in rotation was more, and in some very much more, than in the beans so grown. Without manure, it averaged only about 1 ton per acre per annum; with superphosphate, in one case more than 2, and in the other more than 2½ tons; and in each with the full manure, including potash and nitrogen, more than 3 tons.

Lastly, the average production of dry substance in the six crops of beans and two of clover, taken together, was, without manure, only about three-fourths of a ton; with superphosphate, in one case little more than 1 ton, and in the other rather more than 1¼ tons; and with the mixed manure, in both cases less than 1¾ tons. These amounts in the leguminous crops with the mixed manure were, however, greater than those obtained in the turnip crops, but less than those in either the barley or the wheat grown in rotation. The significance of the amounts grown in the leguminous crops will, however, be the more clearly recognized when we come to consider the quantities of nitrogen in the different crops, and also the fact of the large proportion of the manurial constituents of the leguminous crops grown in rotation, that will generally be retained on the farm.

THE DRY MATTER IN THE WHEAT CROPS.

The bottom division of Table 60 (p. 195) shows the average amounts of dry substance in the wheat—grain, straw, and total produce—grown in rotation, and those obtained in the same years in another field under, as far as possible, parallel conditions as to manuring, but grown continuously—that is, year after year on the same land.

A glance at the figures shows that, both without manure and with superphosphate alone, the amount of dry matter produced was, both in grain and straw, in each case considerably less than half as much in

the crops grown continuously as in those grown in rotation; and that, even with the mixed manure supplying both mineral constituents and nitrogen, it was considerably less in the continuous than in the rotation crops.

So far as the unmanured and the superphosphate crops are concerned, it is obvious that the growth year after year must be much more exhausting, both of nitrogen and of certain essential mineral constituents, in a condition of composition and of distribution within the soil and subsoil available to one particular crop than when it is grown in alternation with others of different requirements, habits, and root ranges.

It has been explained that in the case of the mixed manure rotation plats there was applied for the first crop of the course, besides a full supply of mineral constituents, about 140 pounds of nitrogen; at the average rate, therefore, of 35 pounds per acre per annum over the four years. But, in the case of the continuously grown wheat crops, not only a full supply of mineral manure but 43 pounds of nitrogen as ammonium salts were directly applied every year. The fact of the greater amount of produce on the rotation plats would indicate, therefore, that notwithstanding the growth and removal of the intermediate crops since the application of the manure for the roots, there was more nitrogen, and more of other constituents also, in a condition of composition and of distribution available for the wheat than in the case of the annual direct supply.

Of course, the proportion of grain and of straw in a wheat crop varies, as it also does in barley, according to variety, soil, season, and other circumstances. It is seen that, in the experimental crops, whether grown in rotation or continuously, there was always much more of the produced dry matter accumulated in the straw than in the grain. Indeed, there was in some cases nearly twice as much. On the assumption, therefore, that as a rule the grain will be sold and the straw retained on the farm as food and litter, very much more than half of the produced dry matter will be so retained.

Comparing the amounts of dry matter accumulated in the different rotation crops, and taking as the most normal the quantities obtained under the influence of the mixed manure, including nitrogen, it is seen that, on the average, the two cereal crops, the barley and the wheat, produced approximately equal amounts, and each considerably more than either of the fallow crops, the roots or the Leguminosæ.

THE AMOUNTS OF NITROGEN IN THE ROTATION AND IN THE CONTINUOUS CROPS.

Table 61 shows the average amounts of nitrogen per acre per annum over the eight years in the rotation and in the continuous crops, respectively.

TABLE 61.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eight courses, thirty-two years, 1852–1883).*

[Average amounts of nitrogen per acre in rotation compared with those in crops grown continuously.]

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Swedish turnips.												
Roots:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	9.4	5.8	8.5	5.3	28.7	26.8	32.9	32.2	66.3	66.7	68.2	65.5
Continuous[1]	6.8	6.8	6.8	6.8	13.6	13.6	13.6	13.6	40.1	40.1	40.1	40.1
Rotation + or — continuous	2.6	1	1.7	1.5	15.1	13.2	19.3	18.6	26.2	26.6	28.1	25.4
Leaves:												
Rotation	2.1	1.8	1.9	1.6	6.1	6.5	6.9	7.6	12.2	13.9	13	13.9
Continuous[1]	2	2	2	2	5.8	5.8	5.8	5.8	14.1	14.1	14.1	14.1
Rotation + or — continuous	.1	—.2	—.1	—.4	.3	.7	1.1	1.8	—1.9	—.2	—1.1	—.2
Total:												
Rotation	11.5	7.6	10.4	[2]6.9	34.8	33.3	39.8	39.8	78.5	80.6	81.2	79.4
Continuous	8.8	8.8	8.8	8.8	19.4	19.4	19.4	19.4	54.2	54.2	54.2	54.2
Rotation + or — continuous	2.7	—1.2	1.6	—1.9	15.4	13.9	20.4	20.4	24.3	26.4	27	25.2
Barley.												
Grain:												
Rotation	21.5	23	21.5	20.1	17.8	17.8	22.9	24.6	29.7	30.7	35	34.9
Continuous	13.5	13.5	13.5	13.5	15.5	15.5	15.5	15.5	35.2	35.2	35.2	35.2
Rotation + or — continuous	8	9.5	8	6.6	2.3	2.3	7.4	9.1	—5.5	—4.5	—.2	—.3
Straw:												
Rotation	6.6	7.4	6.6	6.6	5.5	5.7	7.5	7.9	9.5	10	12.5	11.9
Continuous	4.2	4.2	4.2	4.2	4.5	4.5	4.5	4.5	11.4	11.4	11.4	11.4
Rotation + or — continuous	2.4	3.2	2.4	2.4	1	1.2	3	3.4	—1.9	—1.4	1.1	.5
Total:												
Rotation	28.1	30.4	28.1	[2]26.7	23.3	23.5	30.4	32.5	39.2	40.7	47.5	46.8
Continuous	17.7	17.7	17.7	17.7	20	20	20	20	46.6	46.6	46.6	46.6
Rotation + or — continuous	10.4	12.7	10.4	9	3.3	3.5	10.4	12.5	—7.4	—5.9	.9	.2
Beans (6 courses), clover (2 courses), or fallow.												
Corn:												
Rotation	......	27.5	......	27.2	......	30.4	......	36.6	......	49.6	......	55.7
Continuous	......	9.7	......	9.7	......	10.5	......	10.5	......	21.4	......	21.4
Rotation + or — continuous	......	17.8	......	17.5	......	19.9	......	26.1	......	28.2	......	34.3
Straw:												
Rotation	......	9.4	......	8.9	......	10.1	......	12.4	......	14	......	14.5
Continuous	......	4.6	......	4.6	......	5.5	......	5.5	......	7.1	......	7.1
Rotation + or — continuous	......	4.8	......	4.3	......	4.6	......	6.9	......	6.9	......	7.4
Total:												
Rotation	......	36.9	......	36.1	......	40.5	......	49	......	63.6	......	70.2
Continuous	......	14.3	......	14.3	......	16	......	16	......	28.5	......	28.5
Rotation + or — continuous	......	22.6	......	21.8	......	24.5	......	33	......	35.1	......	41.7

[1] Average nineteen years, 1849–1852 and 1856–1870. [2] Probably crop too low owing to a dell.

TABLE 61.—*Experiments on the rotation of roots, barley, clover, etc.*—Continued.

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Beans (6 courses), etc.—Continued.												
Clover:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	......	55	......	[1]47	......	124.5	......	144.6	......	167	......	168.4
Continuous	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)
Average of 8 courses, beans and clover	......	41.5	......	[1]38.9	......	61.5	......	72.9	......	89.5	......	94.7
Wheat.												
Grain:												
Rotation	26.2	23.7	25.5	21.5	27.2	25.4	28.6	28.2	28.9	30.1	27.7	30.1
Continuous	11.6	11.6	11.6	11.6	13.9	13.9	13.9	13.9	23.9	23.9	23.9	23.9
Rotation + or — continuous	14.6	12.1	13.9	9.9	13.3	11.5	14.7	14.3	5.0	6.2	3.8	6.2
Straw:												
Rotation	10.4	9.1	9.9	8.2	11.8	10.5	12.3	11.7	13.2	13.6	13.8	13.1
Continuous	5.4	5.4	5.4	5.4	5.9	5.9	5.9	5.9	10.1	10.1	10.1	10.1
Rotation + or — continuous	5	3.7	4.5	2.8	5.9	4.6	6.4	5.8	3.1	3.5	3.7	3
Total:												
Rotation	36.6	32.8	35.4	[1]29.7	39	35.9	40.9	39.9	42.1	43.7	41.5	43.2
Continuous	17	17	17	17	19.8	19.8	19.8	19.8	34	34	34	34
Rotation + or — continuous	19.6	15.8	18.4	12.7	19.2	16.1	21.1	20.1	8.1	9.7	7.5	9.2

[1] Probably crops too low owing to a dell.

THE NITROGEN IN THE ROOT CROPS.

Without manure, with extremely small crops, but very abnormally high percentage of nitrogen in them, the amounts per acre were, in the continuously grown crops only about twice as much as annually comes down as combined nitrogen in the rain and the minor aqueous deposits from the atmosphere; while even in the rotation crops the amounts average but little more than in the continuous.

With superphosphate alone, much larger crops, but much lower percentages of nitrogen, there was very much more nitrogen taken up than without manure; in fact, when grown in rotation from three to four times as much, and when grown continuously more than twice as much. There was, too, very much more in the rotation than in the continuous crops. The detailed results given in Section I, relating to the continuous growth of root crops afford conclusive evidence that the increased amount of nitrogen taken up by the crop under the influence of phosphatic manures is derived from the resources of the soil itself by the aid of the greatly enhanced development of fibrous feeding root induced by such manures.

With the mixed manure containing nitrogen there was, as with superphosphate alone, much more nitrogen taken up under rotation than with continuous growth. But, under rotation, there was about twice as much taken up with the mixed manure containing nitrogen as with superphosphate without nitrogen, and with continuous growth there was nearly three times as much taken up as with superphosphate without nitrogen. It is clear, therefore, that the crops, whether grown in rotation or continuously, took up much of the nitrogen supplied by the manure. Indeed, it can not be doubted that beyond the small amount of combined nitrogen annually coming down from the atmosphere in rain and the minor aqueous deposits, the source of the large amount of nitrogen of root crops is the stores of it within the soil, whether this be due to accumulations or to direct supply by manure. On the other hand, the large amounts of produce obtained by the aid of nitrogenous manures on land to which no carbonaceous manure has been applied for about fifty years is evidence that the atmosphere is at any rate the chief, if not the exclusive, source of the carbon of the crops.

Lastly, as to the results in the table relating to the Swedish turnips, it is seen that by far the greater part of the nitrogen of the crops was accumulated in the edible root.

THE NITROGEN IN THE BARLEY CROPS.

The second division of Table 61 (p. 201) shows the average amounts of nitrogen per acre per annum over the eight years, in the rotation and in the continuous barley crops, respectively.

Referring to the results chiefly in their bearing on the question of the position of the barley crop in rotation, and of its dependence, or otherwise, on the soil for its supplies of nitrogen, the amounts of it in the total crops, grain and straw together, are of most interest.

When considering similar results relating to the first crop of the course—the Swedish turnips—it was seen that the average amount of nitrogen per acre per annum in the total crops, roots and leaves together, was only 10 or 11 pounds, or even less, when grown without any manure. The results relating to the rotation barley crops show, however, that the average annual removal in them was without manure nearly 30 pounds; the conditions of growth being substantially equivalent to fallow, as practically no root crop had been removed.

Consistently with other evidence on the point, the amounts of nitrogen removed in the barley crops grown on the superphosphate plats are seen to be even considerably less than without manure, where the increased crop of roots grown under the influence of the superphosphate had been removed from the land; but where the superphosphate turnips had been fed on the land, the amounts of nitrogen removed in the barley crops are more than under the parallel conditions without manure. In other words, an increased amount of nitrogen having been taken up from the soil by the turnips under the influence of the super-

phosphate, the land was left poorer in available nitrogen for the barley where the increased turnip crop had been removed from the land, but richer where it, or its manurial residue, was left upon it.

Again, under the influence of the mixed manure, supplying a liberal amount of nitrogen for the roots, which took up a considerable quantity of it, there was much less nitrogen in the succeeding barley where the roots so grown had been removed than where they or their manurial residue had been left on the land.

The actual quantities of nitrogen removed in the barley crops, where the roots had previously been removed, were: Without manure, nearly 30 pounds; with superphospate, about 23½ pounds; and with the mixed manure, about 40 pounds. But where the roots had been fed or left on the land, they were: Without manure, about 28 pounds; with superphosphate, more than 30 pounds; and with the mixed manure containing nitrogen, about 47 pounds.

Comparing the amounts of nitrogen taken up by the rotation with those by the continuously grown barley, it is seen, as might be expected under the conditions described, that both without manure and with superphosphate the rotation barley took up much more than the continuously grown. Where, however, nitrogenous manure had been applied for the roots, and they had been removed, the succeeding barley took up less nitrogen than the continuous crops which annually received nitrogenous manure; but where the roots had not been removed from the land the nitrogen was nearly the same in the rotation and in the continuously grown barley—about 47 pounds per acre per annum.

The influence of the manuring, and of the amount and treatment of the previous root crop, on the available supply of nitrogen within the soil for the succeeding barley is, therefore, throughout clearly traceable.

Lastly, in regard to the nitrogen statistics of the barley-crops, it is to be observed that, under whatever conditions of manuring or other treatment and whether grown in rotation or continuously, there was generally three-fourths or more of the total nitrogen of the crop accumulated in the grain, that is, in the portion which is as a rule sold off the farm; only about one-fourth therefore remaining in the straw, which is supposed to be retained on the farm.

THE NITROGEN IN THE LEGUMINOUS CROPS.

The third division of Table 61 (p. 201) gives the results relating to this point.

Referring first to the amounts of nitrogen in the total bean crops (corn and straw together), it is seen that, under each of the three conditions as to manuring, there was from twice to twice and a half as much in the rotation as in the continuously grown beans. The details further show that the advantage was proportionally greater in the corn than in the straw.

It is next to be observed that the amounts of nitrogen taken up by the rotation beans were, without manure, about 36 pounds per acre per annum, and with superphosphate, between 40 and 50 pounds; while with the mixed manure containing nitrogen there were in one case 63.6 pounds, and in the other 70.2 pounds. In fact, both without manure and with superphosphate, the amounts taken up in the beans were much greater than in either the preceding roots or the preceding barley. With the mixed manure supplying nitrogen, they were also much more than in the preceding barley, but less than in the root crops, to which the mixed manure had been directly applied.

The point of greatest interest in the results is, however, that under each condition as to manuring, the clover took up very much more nitrogen than the beans, and very much more than either of the other crops of the rotation under parallel conditions. Thus, even without manure, the average amount of nitrogen in the two crops of clover was in one case 55 pounds, and in the other 47 pounds; with superphosphate it was 124.5 and 144.6 pounds; and with the mixed manure, containing both potash and nitrogen, in the one case 167 pounds, and in the other 168.4 pounds. Or, taking the average amount of nitrogen in the six bean and two clover crops, there were, without manure, 41.5 and 38.9 pounds; with superphosphate, 61.5 and 72.9 pounds; and with the mixed manure, 89.5 and 94.7 pounds. It is, indeed, to the occasional growth of clover that the very large average amounts of nitrogen removed in the leguminous crops of the rotation are to be attributed; and it is these amounts that have to be taken into consideration in comparing the effects on the yield of the other crops of the rotation, and of the rotation as a whole on the one hand of growing a leguminous crop, and on the other of fallowing, which, of course, neither yields nor removes nitrogen, unless by loss in drainage.

Further, the figures show that there was generally three, or even more, times as much of the total nitrogen of the bean crops accumulated in the corn as remained in the straw. Lastly, not only does the leguminous crop of the rotation yield the most nitrogen, but, unless in the case of some of the corn of the beans, the whole of it is supposed to be retained on the farm, and there is, in addition, more or less, and sometimes a considerable amount, of nitrogenous crop residue left within the soil for succeeding crops.

THE NITROGEN IN THE WHEAT CROPS.

The results on this head are recorded in the bottom division of Table 61 (p. 202).

Referring first to the amounts of nitrogen in the total produce (grain and straw together), it is seen that both without manure and with superphosphate alone; that is, with the greatest exhaustion, especially of nitrogen, there was generally about, or even more than, twice as much in the rotation as in the continuous crops. With the full manure, both

mineral and nitrogenous, applied for the rotation crops only at the beginning of the course, but for the continuous ones each year for the wheat crop to be grown, the relative deficiency in the continuous crops was, however, very much less. Thus, the figures show that the average amounts of nitrogen in the total wheat crops were: Without manure, nearly 35 pounds per acre per annum in the rotation crops, and only 17 pounds in the continuous ones; with the superphosphate alone nearly 40 pounds under rotation, but in the continuous crops not 20 pounds; and lastly, with the full manure there was an average of more than 42 pounds in the rotation crops, and of 34 pounds in those grown continuously. There is direct evidence, therefore, that there was, under all conditions, more nitrogen available to the crops grown in rotation than to those growing year after year on the same land; and the advantage is relatively much the greater where no nitrogen had been supplied in manure. The beneficial effect of the interpolation of other crops with the cereals is therefore very obvious.

In the case of the second crop of the course, the barley, it was shown that without manure the increased produce in rotation was due to scarcely any roots having been grown, so that the land was practically fallowed for the barley; and now in the case of the fourth crop, the wheat, there was the preparation either of the growth of a leguminous crop, leaving a highly nitrogenous residue, or of fallowing. Then with superphosphate alone, the produce of barley, and the yield of nitrogen in it, were less than without manure where the turnips had been removed, but more where they had not, and where, therefore, there was an available nitrogenous residue from the roots; and now in the wheat the effects on the available supply of nitrogen, on the one hand of the growth and removal of a leguminous crop, and on the other of actual fallow, are observable. Lastly, with the mixed manure the influence of the direct supply of nitrogen for the first crop of the course is obvious. But, as the amounts of nitrogen taken up were not very much more than where none had been supplied, it is evident that in both cases much must have been due to the influence of the preceding leguminous crop or fallow.

Upon the whole there can be no question that, so far as nitrogen is concerned, the supply within the soil in a condition of combination and of distribution available to the wheat is increased, both by fallow and by the growth of a leguminous crop, especially of clover; and further, that such accumulation of available nitrogen by fallow, and of nitrogenous crop residue by the growth of leguminous crops, is the greater when the soil and subsoil are not abnormally exhausted of organic nitrogen.

Lastly, it is to be observed that under all conditions of manuring, or other treatment, there was, both in the rotation and in the continuous wheat crops, more than twice, and in some cases considerably more than twice, as much of the total nitrogen of the produce stored up in

the grain as in the straw. Hence, in the sale of the grain, and the retention of the straw for home use, by far the greater part of the nitrogen of the crop is exported from the farm.

THE AMOUNTS OF TOTAL MINERAL MATTER (ASH) IN THE ROTATION AND IN THE CONTINUOUS CROPS.

The results are given in Table 62, for each of the four descriptions of crop, in exactly the same form as those for the total dry matter and the nitrogen in Tables 60 and 61 (pp. 195, 201), respectively.

TABLE 62.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eight courses, thirty-two years, 1852–1883).*

[Average amounts of mineral matter (ash) per acre in rotation, compared with those in crops grown continuously.]

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Swedish turnips.												
Roots:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	15.7	9.5	13.8	8.8	74.1	71.3	82.5	81.9	167.8	171.2	182.4	172.3
Continuous[1]	10.9	10.9	10.9	10.9	40	40	40	40	100.3	100.3	100.3	100.3
Rotation + or — continuous	4.8	—1.4	2.9	—2.1	34.1	31.3	42.5	41.9	67.5	70.9	82.1	72
Leaves:												
Rotation	6.7	6	6.6	5.9	17.9	20.4	19.2	22.9	35.2	41.9	40.1	41.6
Continuous[1]	5.9	5.9	5.9	5.9	16.4	16.4	16.4	16.4	40.5	40.5	40.5	40.5
Rotation + or — continuous	.8	.1	.7	.0	1.5	4	2.8	6.5	—5.3	1.4	—.4	1.1
Total:												
Rotation	22.4	15.5	20.4	[2]14.7	92	91.7	101.7	104.8	203	213.1	222.5	213.9
Continuous[1]	16.8	16.8	16.8	16.8	56.4	56.4	56.4	56.4	140.8	140.8	140.8	140.8
Rotation + or — continuous	5.6	—1.3	3.6	—2.1	35.6	35.3	45.3	48.4	62.2	72.3	81.7	73.1
Barley.												
Grain:												
Rotation	34.8	35.9	34.2	30.7	34.9	33.8	44.1	45.9	50.7	51.5	58.1	57.7
Continuous	21.5	21.5	21.5	21.5	28.4	28.4	28.4	28.4	58.8	58.8	58.8	58.8
Rotation + or — continuous	13.3	14.4	12.7	9.2	6.5	5.4	15.7	17.5	—8.1	—7.3	—.7	—1.1
Straw:												
Rotation	81.3	87.5	79.2	76.1	75.6	77.7	96.9	99.8	113.5	116.8	145.6	144.9
Continuous	47.3	47.3	47.3	47.3	55.6	55.6	55.6	55.6	130.6	130.6	130.6	130.6
Rotation + or — continuous	34	40.2	31.9	28.8	20	22.1	41.3	44.2	—17.1	—13.8	15	14.3
Total:												
Rotation	116.1	123.4	113.4	[2]106.8	110.5	111.5	141	145.7	164.2	168.3	205.7	202.6
Continuous	68.8	68.8	68.8	68.8	84	84	84	84	189.4	189.4	189.4	189.4
Rotation + or — continuous	47.3	54.6	44.6	38	26.5	27.5	57	61.7	—25.2	—21.1	14.3	13.2

[1] Average nineteen years, 1849–1852 and 1856–1870. [2] Probably crop too low owing to a dell.

TABLE 62.—*Experiments on the rotation of roots, barley, clover, etc.*—Continued.

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Beans (6 courses) clover (2 courses), or fallow.												
Corn:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	......	18.5	......	18.4	......	20.2	......	24.1	......	35.8	......	40.7
Continuous	......	7.6	......	7.6	......	9.4	......	9.4	......	21.1	......	21.1
Rotation + or − continuous	......	10.9	......	10.8	......	10.8	......	14.7	......	14.7	......	19.6
Straw:												
Rotation	......	53.1	......	53.3	......	65.8	......	72.5	......	87.7	......	90.8
Continuous	......	28.5	......	28.5	......	35.1	......	35.1	......	54.2	......	54.2
Rotation + or − continuous	......	24.6	......	24.8	......	30.7	......	37.4	......	33.5	......	36.6
Total:												
Rotation	......	71.6	......	71.7	......	86.0	......	96.6	......	123.5	......	131.5
Continuous	......	36.1	......	36.1	......	44.5	......	44.5	......	75.3	......	75.3
Rotation + or − continuous	......	35.5	......	35.6	......	41.5	......	52.1	......	48.2	......	56.2
Clover:												
Rotation	......	198.3	......	[1]172.6	......	421.3	......	487.5	......	569.8	......	612.5
Continuous	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)
Average of 8 courses, beans and clover	......	103.3	......	[1]96.9	......	169.8	......	194.3	......	235.1	......	251.7
Wheat.												
Grain:												
Rotation	26.3	24.6	25.6	22.1	29.6	29.1	30	31.1	30.6	33.3	29.5	33.2
Continuous	13.6	13.6	13.6	13.6	16.3	16.3	16.3	16.3	25	25	25	25
Rotation + or − continuous	12.7	11	12	8.5	13.3	12.8	13.7	14.8	5.6	8.3	4.5	8.2
Straw:												
Rotation	167.9	157.9	160.9	143.5	181.4	172.4	182.5	182	187.9	198.9	190.7	196.7
Continuous	74.4	74.4	74.4	74.4	89.3	89.3	89.3	89.3	136.7	136.7	136.7	136.7
Rotation + or − continuous	93.5	83.5	86.5	69.1	92.1	83.1	93.2	92.7	51.2	62.2	54	60
Total:												
Rotation	194.2	182.5	186.5	[1]165.6	211	201.5	212.5	213.1	218.5	232.2	220.2	229.9
Continuous	88	88	88	88	105.6	105.6	105.6	105.6	161.7	161.7	161.7	161.7
Rotation + or − continuous	106.2	94.5	98.5	77.6	105.4	95.9	106.9	107.5	56.8	70.5	58.5	68.2

[1] Probably crop too low owing to a dell.

The record is deserving of careful study, as showing the very various, and sometimes very large, amounts of mineral or ash constituents taken up from the soil and stored up in the different crops or parts of the crops. But it must suffice here to direct attention to some of the points of chief interest brought to view on the consideration of the amount, and of the distribution of some of the more important individual mineral constituents in the respective crops; and for the purposes of such an illustration reference will chiefly be made to the amounts of phosphoric acid, and of potash, but in some cases to that of lime also, in the crops.

THE AMOUNTS OF PHOSPHORIC ACID IN THE ROTATION AND IN THE CONTINUOUS CROPS.

Table 63 records the results relating to the amounts of phosphoric acid in the different crops or parts of crops.

TABLE 63.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eight courses, thirty-two years, 1852–1883).*

[Average amounts of phosphoric acid per acre, in rotation compared with those in crops grown continuously.]

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Swedish turnips.												
Roots:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	1.26	0.77	1.11	0.71	7.91	7.68	8.83	8.78	16.67	17.02	18.14	17.12
Continuous [1]	.88	.88	.88	.88	4.14	4.14	4.14	4.14	9.91	9.91	9.91	9.91
Rotation + or − continuous	.38	−.11	.23	−.17	3.77	3.54	4.69	4.64	6.76	7.11	8.23	7.21
Leaves:												
Rotation	.29	.25	.28	.25	1.27	1.44	1.36	1.62	2.79	3.17	3.04	3.16
Continuous [1]	.25	.25	.25	.25	1.16	1.16	1.16	1.16	3.07	3.07	3.07	3.07
Rotation + or − continuous	.04	.00	.03	.00	.11	.28	.20	.46	−.28	.10	−.03	.09
Total:												
Rotation	1.55	1.02	1.39	[2].96	9.18	9.12	10.19	10.40	19.46	20.19	21.18	20.28
Continuous [1]	1.13	1.13	1.13	1.13	5.30	5.30	5.30	5.30	12.98	12.98	12.98	12.98
Rotation + or − continuous	.42	−.11	.26	−.17	3.88	3.82	4.89	5.10	6.48	7.21	8.20	7.30
Barley.												
Grain:												
Rotation	11.24	11.59	11.02	9.89	12.29	11.91	15.52	16.16	18.34	18.63	21.04	20.90
Continuous	6.95	6.95	6.95	6.95	10	10	10	10	21.31	21.31	21.31	21.31
Rotation + or − continuous	4.29	4.64	4.07	2.94	2.29	1.91	5.52	6.16	−2.97	−2.68	−.27	−.41
Straw:												
Rotation	1.87	2.03	1.82	1.74	1.80	1.85	2.32	2.38	2.87	2.96	3.68	3.53
Continuous	1.10	1.10	1.10	1.10	1.33	1.33	1.33	1.33	3.30	3.30	3.30	3.30
Rotation + or − continuous	.77	.93	.72	.64	.47	.52	.99	1.05	−.43	−.34	.38	.23
Total:												
Rotation	13.11	13.62	12.84	[2]11.63	14.09	13.76	17.84	18.54	21.21	21.59	24.72	24.43
Continuous	8.05	8.05	8.05	8.05	11.33	11.33	11.33	11.33	24.61	24.61	24.61	24.61
Rotation + or − continuous	5.06	5.57	4.79	3.58	2.76	2.43	6.51	7.21	−3.40	−3.02	.11	−.18
Beans (6 courses), clover (2 courses), or fallow.												
Corn:												
Rotation	......	5.15	......	5.14	......	6.81	......	8.18	......	11.49	......	13.05
Continuous	......	2.11	......	2.11	......	3.16	......	3.16	......	6.75	......	6.75
Rotation + or − continuous	......	3.04	......	3.03	......	3.65	......	5.02	......	4.74	......	6.30

[1] Average nineteen years, 1849–1852 and 1856–1870. [2] Probably crop too low owing to a dell.

TABLE 63.—*Experiments on the rotation of roots, barley, clover, etc.*—Continued.

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Beans (6 courses), etc.—Continued.												
Straw:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	......	1.17	......	1.17	......	1.78	......	1.97	......	1.99	......	2.06
Continuous	......	.63	......	.63	......	.95	......	.95	......	1.24	......	1.24
Rotation + or − continuous	......	.54	......	.54	......	.83	......	1.02	......	.75	......	.82
Total:												
Rotation	......	6.32	......	6.31	......	8.59	......	10.15	......	13.48	......	15.11
Continuous	......	2.74	......	2.74	......	4.11	......	4.11	......	7.99	......	7.99
Rotation + or − continuous	......	3.58	......	3.57	......	4.48	......	6.04	......	5.49	......	7.12
Clover:												
Rotation	......	8.04	......	[1]16.96	......	20.30	......	22.99	......	31.69	......	34.29
Continuous	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)
Average of 8 courses, beans and clover	......	6.75	......	[1]16.48	......	11.52	......	13.36	......	18.03	......	19.90
Wheat.												
Grain:												
Rotation	12.53	11.18	12.19	10.50	14.48	14.23	14.68	15.25	15.12	16.50	14.58	16.43
Continuous	6.45	6.45	6.45	6.45	7.99	7.99	7.99	7.99	12.40	12.40	12.40	12.40
Rotation + or − continuous	6.08	4.73	5.74	4.05	6.49	6.24	6.69	7.26	2.72	4.10	2.18	4.03
Straw:												
Rotation	2.87	2.73	2.76	2.48	3.87	3.75	3.84	3.95	4.94	5.46	5.00	5.31
Continuous	1.27	1.27	1.27	1.27	1.88	1.88	1.88	1.88	3.62	3.62	3.62	3.62
Rotation + or − continuous	1.60	1.46	1.49	1.21	1.99	1.87	1.96	2.07	1.32	1.84	1.38	1.69
Total:												
Rotation	15.40	13.91	14.95	[1]12.98	18.35	17.98	18.52	19.20	20.06	21.96	19.58	21.74
Continuous	7.72	7.72	7.72	7.72	9.87	9.87	9.87	9.87	16.02	16.02	16.02	16.02
Rotation + or − continuous	7.68	6.19	7.23	5.26	8.48	8.11	8.65	9.33	4.04	5.94	3.56	5.72

[1] Probably crop too low owing to a dell.

THE PHOSPHORIC ACID IN THE ROOT CROPS.

The figures show that without manure the rotation turnip crops took up an extremely small amount of phosphoric acid, reaching in only one case to an average of 1½ pounds per acre per annum. By superphosphate alone the amount was increased to an average of about 10 pounds, and, although this increase only represents about one-tenth of the phosphoric acid applied in manure, it is very important, as it is directly connected with the greatly increased development of fibrous feeding root within the soil, which is a special effect of phosphatic manures when applied to turnips; and it is by virtue of this development that these crops so markedly exhaust the available nitrogen within the soil, and especially the surface soil. As has been shown,

there is abundant evidence that the increased amount of nitrogen taken up under the influence of phosphates unaccompanied by any supply of nitrogen itself, is at the expense of the stores of the soil; and that it is not due to a capacity to take up either combined or free nitrogen from the atmosphere, by virtue of an increased development of leaf surface, under the influence of the phosphatic manure.

With the mixed manure, supplying, besides superphosphate, salts of potash, soda, and magnesia, and a liberal amount of nitrogen as well, there was, although the supply of phosphoric acid by manure was exactly the same, now about twice as much of it taken up, as a coincident of the greatly increased growth, due partly to the other mineral constituents at the same time added, but especially to the influence of the increased available supply of nitrogen. Still, only a small proportion of the phosphoric acid applied was taken up considering the recognized importance of its application for turnips, and its undoubted specific effects on the growth as above described.

Comparing the amounts of phosphoric acid in the rotation crops with those in the continuous ones, the equally small, or even smaller, amount taken up without manure by the latter is further confirmation of the incapability of this assumed restorative crop to yield any practical amount of produce without adequate soil supplies. With superphosphate alone, as also with the mixed manure, the continuous crop took up little more than half as much phosphoric acid as the rotation ones under the assumed fairly parallel conditions as to manuring. The deficiency is, however, obviously not due to any deficiency of supply within the soil, but is only a coincident of the less total growth, attributable to a great extent, as has been explained, to the unfavorable mechanical condition of the soil, induced by the continuous growth of the crop.

Lastly, in regard to the phosphoric acid in the turnip crops, it is to be observed that in all cases much more was accumulated in the edible roots than in the leaves, which remain only for manure again. Indeed, in the case of the most normal crops, those grown in rotation with the full mixed manure, there was five or six times as much accumulated in the roots as in the leaves.

THE PHOSPHORIC ACID IN THE BARLEY CROPS.

Looking first to the amounts in the total produce, grain and straw together, and to the portions of the rotation plats from which the previous root crops had been removed, it is seen that without manure rather more than 13 pounds of phosphoric acid was, on the average, annually removed in the barley crops; and where superphosphate had previously been applied for the roots the succeeding barley took up only about 14 pounds—that is, scarcely any more than without the supply of it. But where the mixed manure, including nitrogen, had been applied for the roots there was about one-and-a-half times as

much, or rather over 21 pounds, of phosphoric acid in the succeeding barley crops. Then, where the root crops had not been removed from the land, the amounts of phosphoric acid in the succeeding barley crops were, without manure, about 12 pounds per acre, with superphosphate about 18 pounds, and with the mixed manure nearly 25 pounds. In the case of the phosphoric acid, therefore, as in that of the nitrogen, the influence of the manuring and other treatment of the preceding crop of the course is clearly reflected in the amounts taken up in the succeeding barley.

Comparing the amounts of phosphoric acid in the rotation barley crops with those in the continuously grown ones, it is seen that both without manure and with superphosphate the rotation crops took up considerably the most phosphoric acid; and this was the case notwithstanding that the continuously grown crops were annually manured with superphosphate, while for those grown in rotation the application had only been for the preceding crop, the turnips. The less assimilation in the case of the continuous crops was doubtless due to the diminished total growth, which in its turn was due to the greater exhaustion of the available nitrogen of the soil with the annual growth. Consistently with this view, where the mixed manure, supplying an abundance of nitrogen was applied, and the crops, both rotation and continuous, were pretty full averages for the particular soil and the seasons of growth, the amounts of phosphoric acid in the rotation crops, where the roots had not been removed, were almost identical with those in the continuous crops. Where, however, the rotation roots had been removed, carrying off therefore the whole of the nitrogen that had been taken up, the succeeding barley crops were accordingly not full for the seasons of their growth, and the amounts of phosphoric acid in them were less than in the continuously grown crops.

The figures relating to both the rotation and the continuous barley further show that about six-sevenths of the total phosphoric acid of the crops is accumulated in the grain which is supposed to be sold off the farm. There was, indeed, even a somewhat higher proportion where phosphoric acid was supplied in the manure. Lastly, as in the cases of the total produce, the dry matter and the nitrogen, there is much less difference between the amounts of phosphoric acid taken up under the three different conditions as to manuring than in the case of the turnips; that is, the assumed restorative crop is much more dependent on direct manuring to yield any crop at all than is the cereal crop, which is assumed to be benefited by the interpolation of it.

THE PHOSPHORIC ACID IN THE LEGUMINOUS CROPS.

Referring to the third division of Table 63, it is seen that the amounts of phosphoric acid in the total produce of beans, corn and straw together, was more where superphosphate was supplied than without manure, and more still under the influence of the mixed manure con-

taining, besides superphosphate, salts of potash, soda, and magnesia, and nitrogen also. But, under all three conditions as to manuring, the continuously grown crops take up much less than those grown in rotation. Whether, however, grown in rotation or continuously, three, four, or more times as much of the phosphoric acid is finally accumulated in the corn as remains in the straw. In reference to all the results with beans, however, it is to be borne in mind that under none of the conditions were good crops obtained.

The clover took up without manure little more phosphoric acid than the rotation beans, but with superphosphate the clover took up more than twice as much as the beans; and with the mixed manure it took up more still, and also more than twice as much as the beans grown under the same conditions.

Taking the average of the six crops of beans and two crops of clover grown in the eight courses there was, both without manure and with superphosphate, much less phosphoric acid taken up than in either the preceding barley or the succeeding wheat; and even with the mixed manure, which gave the most normal crops, the average amount of phosphoric acid taken up in the beans and clover was less than in either of the two cereals under the same conditions.

THE PHOSPHORIC ACID IN THE WHEAT CROPS.

The bottom division of Table 63 (p. 209) shows that the rotation wheat, as did the rotation barley, took up very much more phosphoric acid without manure than did either of the so-called fallow crops—the turnips or the leguminous crops. With superphosphate again, both the wheat and barley took up more than either the turnips or the average of the leguminous crops. With the full-mixed manure, however, when each of the four descriptions of crop grew more normally, the amount of phosphoric acid taken up was more nearly uniform in the four cases; the barley, however, then yielding more than the wheat, more than the turnips, more than the average of the leguminous crops, but all considerably less than the average of the two years of clover.

Comparing the amounts of phosphoric acid in the total produce of the rotation with those in the continuously grown wheat, it is seen that there is, without manure, only about half as much taken up in the continuous as in the rotation crops; with superphosphate again, only about half as much in the continuous as in the rotation; but with the more normal growth, when the full mixed manure was annually applied to the continuously grown crops, there was with the fuller produce proportionally much more phosphoric acid taken up; indeed, on the average, about three-fourths as much in the continuous as in the rotation crops.

Lastly, the figures show that by far the larger proportion of the total phosphoric acid in the wheat crops is stored up in the grain, which is assumed to be sold off the farm. Thus, without manure more than four-

fifths, and with superphosphate nearly four-fifths, of the total phosphoric acid of the crops was in the grain. With the mixed manure, however, with rather larger total amounts taken up than with superphosphate alone, there was comparatively little more stored up in the grain, the excess for the most part remaining in the straw. The larger amount of total phosphoric acid taken up with the mixed manure than with superphosphate, the amount supplied by manure being the same in the two cases, is to be attributed to the coincident supply of other constituents in the mixed manure, inducing greater luxuriance, and with it greater activity of collection.

THE AMOUNTS OF POTASH IN THE ROTATION AND IN THE CONTINUOUS CROPS.

The results relating to the amount and distribution of potash in the rotation and continuous crops are recorded in Table 64:

TABLE 64.—*Experiments on the rotation of roots, barley, clover (or beans), or fallow, and wheat, in Agdell field, Rothamsted (eight courses, thirty-two years, 1852–1883).*

[Average amounts of potash per acre in rotation compared with those in crops grown continuously.]

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Swedish turnips.												
Roots:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	5	3.04	4.40	2.82	22.49	21.67	25.05	24.86	66.62	67.99	72.48	38.53
Continuous [1]	3.48	3.48	3.48	3.48	12.08	12.08	12.08	12.08	39.51	39.51	39.51	39.51
Rotation + or — continuous	1.52	—.44	.92	—.66	10.41	9.59	12.97	12.78	27.11	28.48	32.97	29.02
Leaves:												
Rotation	1.07	.95	1.04	.93	2.60	2.96	2.77	3.31	8.66	10.32	9.89	10.25
Continuous [1]	.94	.94	.94	.94	2.38	2.38	2.38	2.38	9.98	9.98	9.98	9.98
Rotation + or — continuous	.13	.01	.10	—.01	.22	.58	.39	.93	—1.32	.34	—.09	.27
Total:												
Rotation	6.07	3.99	5.44	[2]3.75	25.09	24.63	27.82	28.17	75.28	78.31	82.37	78.78
Continuous [1]	4.42	4.42	4.42	4.42	14.46	14.46	14.46	14.46	49.49	49.49	49.49	49.49
Rotation + or — continuous	1.65	—.43	1.02	—0.67	10.63	10.17	13.36	13.71	25.79	28.82	32.88	29.29
Barley.												
Grain:												
Rotation	8.13	8.38	7.97	7.15	8.09	7.85	10.23	10.65	12.33	12.52	14.14	14.04
Continuous	5.03	5.03	5.03	5.03	6.59	6.59	6.59	6.59	14.32	14.32	14.32	14.32
Rotation + or — continuous	3.10	3.35	2.94	2.12	1.50	1.26	3.64	4.06	—1.99	—1.80	—.18	—.28
Straw:												
Rotation	10.83	11.81	10.52	10.09	9.32	9.50	12.10	12.54	18.41	18.97	23.48	23.31
Continuous	6.45	6.45	6.45	6.45	7.03	7.03	7.03	7.03	21	21	21	21
Rotation + or — continuous	4.38	5.36	4.07	3.64	2.29	2.47	5.07	5.51	—2.59	—2.03	2.48	2.31

[1] Average nineteen years, 1849–1852 and 1856–1870. [2] Probably crop too low owing to a dell.

TABLE 64.—*Experiments on the rotation of roots, barley, clover, etc.*—Continued.

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Barley—Continued.												
Total:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	18.96	20.19	18.49	[1]17.24	17.41	17.35	22.33	23.19	30.74	31.49	37.62	37.35
Continuous	11.48	11.48	11.48	11.48	13.62	13.62	13.62	13.62	35.32	35.32	35.32	35.32
Rotation + or — continuous	7.48	8.71	7.01	5.76	3.79	3.73	8.71	9.57	—4.58	—3.83	2.30	2.03
Beans (6 courses), clover (2 courses), or fallow.												
Corn:												
Rotation	......	7.20	......	7.23	......	7.35	......	8.79	......	15.20	......	17.25
Continuous	......	2.98	......	2.98	......	3.46	......	3.46	......	8.94	......	8.94
Rotation + or — continuous	......	4.28	......	4.25	......	3.89	......	5.33	......	6.26	......	8.31
Straw:												
Rotation	......	2.87	......	2.87	......	3.47	......	4.01	......	6.96	......	7.21
Continuous	......	1.54	......	1.54	......	1.82	......	1.82	......	4.33	......	4.33
Rotation + or — continuous	......	1.33	......	1.33	......	1.65	......	2.19	......	2.63	......	2.88
Total:												
Rotation	......	10.13	......	10.10	......	10.82	......	12.80	......	22.16	......	24.46
Continuous	......	4.52	......	4.52	......	5.28	......	5.28	......	13.27	......	13.27
Rotation + or — continuous	......	5.61	......	5.58	......	5.54	......	7.52	......	8.89	......	11.19
Clover:												
Rotation	......	34.18	......	[1]29.67	......	57.63	......	65.48	......	123.12	......	132.62
Continuous	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)
Average of 8 courses, beans and clover	......	16.14	......	[1]14.99	......	22.52	......	25.96	......	47.40	......	51.50
Wheat.												
Grain:												
Rotation	8.65	8.08	8.42	7.26	9.55	9.39	9.69	10.06	9.90	10.82	9.55	10.78
Continuous	4.45	4.45	4.45	4.45	5.27	5.27	5.27	5.27	8.12	8.12	8.12	8.12
Rotation + or — continuous	4.20	3.63	3.97	2.81	4.28	4.12	4.42	4.79	1.78	2.70	1.43	2.66
Straw:												
Rotation	19.12	17.94	18.30	16.31	20.25	19.14	20.45	20.21	25.85	27.47	26.21	27.12
Continuous	8.49	8.49	8.49	8.49	10	10	10	10	18.81	18.81	18.81	18.81
Rotation + or — continuous	10.63	9.45	9.81	7.82	10.25	9.14	10.45	10.21	7.04	8.66	7.40	8.31
Total:												
Rotation	27.77	26.02	26.72	[1]23.57	29.80	28.53	30.14	30.27	35.75	38.29	35.76	37.90
Continuous	12.94	12.94	12.94	12.94	15.27	15.27	15.27	15.27	26.93	26.93	26.93	26.93
Rotation + or — continuous	14.83	13.08	13.78	10.63	14.53	13.26	14.87	15	8.82	11.36	8.83	10.97

[1] Probably crop too low owing to a dell.

THE POTASH IN THE ROOT CROPS.

Before referring to the details on this point, attention should be recalled to the facts fully illustrated in Section I on root crops: That they are essentially sugar crops; that the very characteristic effect which nitrogenous manures exert on their increased growth is mainly represented by a greatly increased production of the nonnitrogenous substance, sugar; that, however the action is to be explained, it is certain that the presence of potash is an important condition of the formation in plants of carbohydrates generally, and that in the case of root crops, the production of the carbohydrate, sugar, is greatly dependent on a liberal available supply of potash.

Referring to the upper division of the table, and for the purpose of the first illustrations to the rotation results, it is seen that, without manure and very abnormally small crops, there was only three, four, or five times as much potash in the roots as in the leaves; with superphosphate, on the other hand, and greatly increased root development, there was eight or nine times as much potash in the roots as in the leaves, and with the mixed manure (including potash) there was, with the further greatly increased actual amount of roots and of potash in them, seven or eight times as much in the roots as in the leaves. That is, there was the greatest accumulation of potash with the greatest accumulation of sugar.

Looking to the actual amounts of potash in the total produce, roots and leaves together, of the rotation crops, it is seen that without manure there was only from 4 to 6 pounds of potash per acre per annum, but with superphosphate, without potash supply, from 25 to 28 pounds; that is, without any supply by manure the plants were able to gather about 20 pounds more potash per acre per annum from the soil itself, by virtue of the greatly increased development of fibrous feeding root under the influence of the phosphatic manure. With the mixed manure, however, containing potash, there was about three times as much of it taken up as with superphosphate alone. But with the supply of potash there was also a liberal supply of available nitrogen, to which the greatly increased growth is largely to be attributed, and with the increased luxuriance much more potash was of course required if there were to be a correspondingly increased formation of the characteristic nonnitrogenous product of the cultivated root sugar. Thus we have without manure only 4 to 6 pounds of potash taken up, with superphosphate (without potash) from 25 to 28 pounds, and with the mixed manure supplying besides phosphoric acid both nitrogen and potash, nearly 80 pounds of potash per acre per annum in the crops.

Comparing the amounts of potash in the rotation crops with those in the continuously grown ones, it is seen that without manure, and practically no growth, there was but little difference in the amounts taken up; with superphosphate there was little more than half as much taken up in the continuous as in the rotation crops; whilst with the mixed manure, with full supply of potash, and much larger amounts of it in

both the rotation and continuous crops, there was rather less than two-thirds as much in the continuous as in the rotation crops. The deficient amounts in the continuous crops, are, however, as in the case of the other constituents, coincidents of the less amounts of produce of the continuous crops, which, as has been pointed out, were, in the case of the superphosphate plat, due partly to the greater exhaustion of available nitrogen of the surface soil with the continuous growth, but partly also to the unfavorable mechanical condition of the soil induced by such growth, and this was probably the chief cause of the deficient produce in the case of the mixed manure crops also.

THE POTASH IN THE BARLEY CROPS.

The second division of Table 64 (p. 214) records the results on this point. In the case of the turnips it was found that much more potash was accumulated in the roots than in the leaves, and this fact was assumed to be connected with the greater amount of the carbohydrate, sugar, in the roots than in the leaves. The results relating to the barley show, however, that there was in every case more, and in some much more, potash in the straw than in the grain. On this point it is to be observed, not only that the root crop is taken up when still in the vegetative stage and its contents are still in the condition of reserve or migratory material, whilst in the case of the cereal the crop is ripened and its constituents are, therefore, more fixed. Further, whilst in the turnip crop there was several times as much dry substance in the roots as in the leaves, in the barley there was even more dry organic substance in the straw than in the grain. Again, in both crops by far the larger proportion of the dry substance consists of carbohydrates —in the one chiefly sugar, and in the other almost exclusively starch and cellulose—the latter making up by far the greater portion of the dry substance of the straw. It is obviously quite consistent that under these circumstances there should be more of the total potash of the barley crop accumulated in the straw than in the grain. It must at the same time be observed that whilst the potash in the grain is comparatively fixed and bears a fairly uniform relation to the amount of dry substance, the quantity which remains in the straw is subject to great variation in proportion to the dry matter, according to the variation in the supply of it within the soil, a great excess above the amount in other cases being sometimes found in the straw. Indeed, the figures show a considerably greater proportion of the total potash of the crop accumulated in the straw where there was a liberal supply of it in manure.

Referring to the amounts of potash taken up in the rotation barley crops on the different plats, according to the manuring or other treatment, the figures show that there was not much difference between the amounts without manure and with superphosphate alone. There was, however, distinctly more taken up on the portions of the superphosphate plat where the roots had not been removed than where they were; and where, therefore, there was conservation for the succeeding crop. With

the mixed manure, however, with its supply of potash as well as of phosphoric acid and nitrogen, the amount of potash in the crops is greatly increased, the increase corresponding closely with the increased amount of produce.

Lastly, in regard to the potash, whilst without manure and with superphosphate alone the rotation barley has gathered much more than the continuously grown, with the mixed manure and full supply of all constituents, the amounts of potash taken up were, as were those of nitrogen and phosphoric acid, nearly the same in the rotation and the continuous crops, where, in rotation the preceding roots had not been removed; but where they had been removed, the amounts of potash in the succeeding barley were less, as were the crops themselves.

THE POTASH IN THE LEGUMINOUS CROPS.

Of all the mineral constituents of the crops, perhaps potash and lime are the most generally recognized as having some distinctive effects when applied as manure for leguminous crops. I have now to refer to the records relating to the potash in these crops as given in the third division of Table 64 (p. 214).

The figures show that, in the case of the beans, unlike that of the cereals, there is much more potash in the corn than in the straw; indeed more than twice as much of the potash of the crops was accumulated in the corn as in the straw, indicating, therefore, a special requirement of it for the formation of the final and most fixed product of the plant—the seed.

Looking to the amounts of potash per acre in the total produce, corn and straw together, of the rotation beans, it is seen that they take up very little more under the influence of the superphosphate than without manure, the quantities averaging about 10 pounds per acre without manure, and scarcely 12 pounds with superphosphate. With the mixed manure, however, directly supplying potash for the previous root crop, the amounts of it taken up were, in the one case 22.16, and in the other 24.46 pounds, or about twice as much as with the superphosphate alone. The influence of the previous supply of potash on the amounts of it taken up in the beans was, in fact, much greater than that of the phosphoric acid on the amounts of it taken up.

But, as in the case of the phosphoric acid, so also in that of the potash, the continuously grown beans took up only about half as much as those grown in rotation; proportionately more, however, where it had been supplied than where it had not. It will be remembered that when discussing the amounts of produce of the bean crops, attention was called to the fact that throughout the experiments a really good agricultural crop was scarcely ever obtained; and this of course must be taken into account when considering the amounts of the several constituents of the crops.

Comparing the amounts of potash stored up in the rotation clover with those in the rotation beans, it is seen that even without manure

and with very small produce, the clover, with its greater root range and longer period of growth, gathered up about three times as much potash as the beans—about 30 pounds against only about 10 pounds in the beans.

With superphosphate alone, while the bean crops contained only 10.82 and 12.80 pounds of potash, the clover contained 57.63 and 65.48 pounds. That is, under the influence of the phosphatic manure, probably partly on the plant and partly on the soil, the clover had accumulated in the removed crop 5 or 6 times as much potash as the beans from the soil itself; while, of the phosphoric acid itself, little more than twice as much was taken up in the clover as in the beans under the influence of the superphosphate without potash. It would thus appear that the beneficial effects of the phosphatic manure on the clover were largely connected with the increased capability of the plant to take up more potash.

With the mixed manure, supplying a large amount of potash, the amount of it found in the clover crops was, however, much greater still. Both in the beans and in the clover the amount of potash in the crops grown under the influence of the direct supply of it was about twice as much as those grown with superphosphate without potash. But while, under the influence of the supply of it, the shorter lived, more meagerly rooting, and less successfully grown bean crops stored up only 22.16 and 24.46 pounds of potash, the clover crops contained in one case 123.12 pounds, and in the other 132.62 pounds.

The very much larger proportion of the total potash of the bean crops, which is found in the corn than in the straw, would seem to indicate its greater importance in connection with the maturing than with the merely vegetative and accumulating tendencies of growth; yet the increased amount of it taken up by the beans coincidently with increased growth, and the much larger amounts of it in the clover with its much greater amounts of growth and produce, and harvested as it is in the unripened condition are, on the other hand, indications of a direct connection between potash supply and the luxuriance of growth or vegetative activity of these leguminous crops. Indeed, as already referred to, potash manures are well known to be frequently beneficial to such crops. To these points I shall have to refer again presently when calling attention to the amount of lime taken up by leguminous crops.

THE POTASH IN THE WHEAT CROPS.

The results on this point are given in the bottom division of Table 64.

It has been seen that by far the larger proportion, both of the nitrogen and of the phosphoric acid of the wheat crops, was accumulated in the grain. But the figures relating to the potash show that of it there was very much more in the straw than in the grain. There was also much more, but not in so great a degree more, in the straw than in the grain of the other cereal—the barley. It has been pointed out that potash is at any rate essentially connected with the formation of the carbohydrates. Consistently with this it was found that by far the

larger proportion of the potash of the turnip crop was in the roots, where was the great accumulation of sugar. Again, of the total potash of the barley crop, the larger proportion was found in the straw where there was the greatest accumulation of carbohydrate—as cellulose; and now, in the wheat, with a larger proportion of straw to grain, and a proportionally larger amount of the total carbohydrates accumulated in the straw, we have in it a still larger proportion of the total potash of the crop. It is, however, to be borne in mind, as has been pointed out, that the straw of both barley and wheat frequently contains, besides the mineral constituents actually essential for the organic formations and changes, a more or less surplus amount taken up as the result of liberal supply, and retained by the plant.

Although there is doubtless clear foundation in fact for the conclusion that the rôle of phosphoric acid is more in connection with the formation and activity of the nitrogenous bodies, and that of the potash with those of the nonnitrogenous compounds, yet it is obvious that in such a view we have only a partial and imperfect explanation of the function of these mineral constituents. Thus, in the case of the beans there was, consistently enough, much more phosphoric acid in the corn than in the straw—that is the more where there was the more nitrogen; but there was also by far the larger proportion of the potash accumulated in the corn, although the greater part of the dry matter of the crop, and with this of its carbohydrates, was in the straw. Indeed, although the leguminous crops are preeminently highly nitrogenous, a liberal supply of potash is essential for their luxuriance; while they contain a higher proportion of it in their dry substance than do the cereals with their higher proportion of carbohydrates.

Reference to the figures shows that the application of superphosphate, without potash, enabled the wheat plant, whether grown in rotation or continuously, to take up an increased, but not a much increased, amount of potash compared with that in the unmanured crops; and that the direct application of it increased the assimilation of it still further; though the increased amount of it stored up represented only a small proportion of that supplied in the manure.

Without manure, the rotation wheat crops contained an average of about 27 pounds of potash, but the continuously grown ones scarcely 13 pounds, or only about half as much. With superphosphate, without potash, the rotation crops gave an average of nearly 30 pounds, and the continuously grown ones little more than 15 pounds; or again only about half as much. That is, when the growing crops had to rely for their potash exclusively on the stores of the soil itself, the rotation crops took up about twice as much as the continuous. Lastly, with the mixed manure supplying potash, the rotation wheat crops gathered nearly 36 pounds after fallow, but about 38 pounds after the leguminous crops, while the continuously grown ones yielded an average of only about 27 pounds. That is, although in the case of the rotation wheat crops three other crops had been grown since the application of

the manure, they took up more potash than the continuously grown ones for which potash was annually supplied.

So much for the results relating to the amounts of the two important and typical mineral constituents—phosphoric acid and potash—taken up by the different crops when grown, respectively, in rotation and continuously, under different conditions as to manuring and other treatment. Similar results relating to other mineral constituents of the crops have been got out, and the discussion of some of them brings to view points of considerable interest, but neither time nor space will admit of their consideration here. It must suffice to refer briefly to the amounts of lime taken up by the leguminous crops under different conditions, a point which has an interesting relation to the results as to the potash taken up by those crops, and to the questions which arose in the discussion of them.

THE AMOUNTS OF LIME IN THE ROTATION AND THE CONTINUOUS LEGUMINOUS CROPS.

Table 65 gives for the leguminous crops alone the amounts of lime in the rotation and in the continuous crops, in the same form in which the phosphoric acid and potash have been given for each of the four crops of the rotation:

TABLE 65.—*Average amounts of lime per acre per annum in the rotation, and in the continuously grown, leguminous crops.*

BEANS (SIX COURSES), CLOVER (TWO COURSES), OR FALLOW.

	Unmanured.				Superphosphate.				Mixed mineral and nitrogenous manure.			
	Roots carted.		Roots fed.		Roots carted.		Roots fed.		Roots carted.		Roots fed.	
	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.	Fallow.	Beans or clover.
Corn:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Rotation	......	1.15	......	1.14	......	1.10	......	1.32	......	2.10	......	2.38
Continuous	......	.47	......	.47	......	.52	......	.52	......	1.24	......	1.24
Rotation + or — continuous	......	.68	......	.67	......	.58	......	.80	......	.86	......	1.14
Straw:												
Rotation	......	14.61	......	14.66	......	17.58	......	19.39	......	24.47	......	25.33
Continuous	......	7.85	......	7.85	......	9.36	......	9.36	......	15.08	......	15.08
Rotation + or — continuous	......	6.76	......	6.81	......	8.22	......	10.03	......	9.39	......	10.25
Total:												
Rotation	......	15.76	......	15.80	......	18.68	......	20.71	......	26.57	......	27.71
Continuous	......	8.32	......	8.32	......	9.88	......	9.88	......	16.32	......	16.32
Rotation + or — continuous	......	7.44	......	7.48	......	8.80	......	10.83	......	10.25	......	11.39
Clover:												
Rotation	......	67.84	......	[1]59.10	......	158.62	......	184.52	......	181.75	......	195.14
Continuous	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)	......	(?)
Average of 8 courses, beans and clover	......	28.78	......	26.63	......	53.67	......	61.66	......	65.36	......	69.57

[1] Probably crop too low owing to a dell.

Very different from what was found to be the case with the potash, it is seen that in the rotation bean crops, a very small proportion of the total amount of lime is accumulated in the corn, ten, twelve, or more times as much being found in the straw. Then the amounts of lime in the total crops were, without manure, between 15 and 16 pounds; with superphosphate, which of course supplied some lime, the quantity was raised to 18.68 and 20.71 pounds, and with the mixed manure also supplying the same amount of lime in its superphosphate, it was further raised to 26.57 and 27.71 pounds. It is further seen that the continuously grown beans contained in corn, straw, and total produce, in some cases only about, and in others not much more than half, as much lime as the rotation ones.

It is remarkable, however, that while without manure the rotation bean crops contained only from 15 to 16 pounds of lime, the clover contained 67.8 and 59.1 pounds; with superphosphate the beans gave 18.68 and 20.71 pounds, and the clover 158.62 and 184.52 pounds, or about eight times as much as the beans; and lastly, with the mixed manure, the bean crops contained 26.57 and 27.71 pounds, and the clover 181.75 and 195.14 pounds of lime, or about seven times as much as the beans.

An increased amount of lime is, therefore, even more directly connected with increased luxuriance and increased production, than is an increased amount of potash taken up. Then, again, the increased amount of potash was apparently more or less directly connected with tendency to maturation or seed formation; but the lime is found chiefly in the straw of the beans, and to be enormously increased in amount in the clover, which does not ripen, but is cut while still in the vegetative condition. The indication is, therefore, that the lime is both actually and as compared with the potash, much more directly connected with the accumulative or vegetative, as distinguished from the maturing processes of the plant. Certain it is at any rate that a largely increased accumulation of lime is a coincident of increased luxuriance in both crops; and it is especially so in the case of the crop, the amount of which depends on the extension of the vegetative stages of development, and the production of a large amount of crude or unripened vegetable substance.

Thus, then, the actual and relative importance of potash and lime in the growth of the highly nitrogenous leguminous crops is clearly illustrated in the acreage amounts given, of potash in the third division of Table 64, and of lime in Table 65. But the study of the percentage composition of the ashes of the crops, and especially of both the percentage composition of the ashes and the amount of the constituents per acre, in the bean plant taken at different stages of its growth, and of somewhat similar results relating to the first, second, and third crops of clover, affords further confirmation of the conclusions which have been drawn from the results already considered. It will be impossible to go into any detail here in regard to these further results, and it must suffice to state very briefly their general indications.

The bean plant ash analyses showed that, on the average, about 75 per cent and at the time of pod formation nearly 80 per cent of the total ash consisted of lime, potash, and carbonic acid. Compared with these results, those relating to the more highly nitrogenous clover, which is not allowed to ripen, but is cut when it reaches the blooming stage, so inducing regrowth and extension of the more specially vegetative stages, show that from about 80 to about 84 per cent of the total ash consisted of lime, potash, and carbonic acid. But while in the ash of the ripened corn-yielding bean crop there was about one-and-a-half times as much potash as lime, in that of the merely vegetating unripened clover there was twice or even three times as much lime as potash. Further, in the ash of the first and third crops of clover, which would be the most succulent and unripe, the relative excess of lime over potash is much greater than in that of the second crop, which develops at the period of the season when the seed-forming tendency is much the greater. Again, in the clover ashes, there was about one-and-a-half times as much carbonic acid as in the ash of the ripened bean plant. It is thus further illustrated that a peculiarity of the composition of these preeminently nitrogen-assimilating elements of rotation is that their ashes consist chiefly of lime, potash, and carbonic acid; that the potash predominates in the ripened and less nitrogen-yielding bean crop, and that the lime and carbonic acid predominate in the continuously vegetating and much more largely nitrogen-accumulating clover.

Referring to the probable or possible significance of these facts, it is obvious that, so far as the nitrogen of the plant is taken up as nitrate of a fixed base, that base, so far as it does not pass back into the roots, will remain in the above-ground parts of the plant, most probably in combination with an organic acid, which will be converted into carbonic acid in the incineration, and be found as such in the ash, if not expelled by an excess of fixed acid or by silica.

In the case of the cereals of the rotation it is probable that most if not all of their comparatively small amount of nitrogen is taken up as nitrate. Potash is by far the predominating base in the ash of the grain, straw, and total produce; lime is in much less amount, both actually and in equivalency; and magnesia is less still, though it is a characteristic constituent of the grain ashes. There is practically no carbonic acid in either wheat or barley grain ash and but little in the straw ash; and if there have been organic acid salts formed with the base of the nitrate, the carbonic acid may have been expelled in the incineration by the excess of fixed acid in the grain ash or by silica in the straw ash.

Taking the produce by the mixed manure as the most normal, the root crops of the rotation come next in amount of nitrogen assimilated over a given area. Potash and lime are the predominating bases. There is much more potash than lime in the more definite product, the root, but the proportion of lime to potash is much greater in the leaf ash, as

would be expected if the nitrogen had been taken up chiefly as calcium nitrate, and the nitric acid subjected to decomposition in the leaves.

Lastly come the Leguminosæ, with their much higher amounts of nitrogen assimilated. These plants also doubtless derive at any rate much nitrogen from nitrates in the soil and subsoil; and it has been shown that their great assimilation of nitrogen is associated with very large amounts of lime and carbonic acid in their ashes.

Referring to the results with the rotation beans grown by the mixed manure, calculation shows that, taking the total crop, corn and straw together, it contained very much less lime than would be required if the whole of its nitrogen had been taken up as calcium nitrate; so that either part of the nitrogen must have been taken up as nitrate of some other base, or in some quite different state of combination, or as free nitrogen; or some of the lime must have been eliminated from the above-ground parts of the plant into the roots, and possibly some of it passed from them into the soil. Again, the amount of carbonic acid found in the ashes of the crop for 100 of nitrogen in it would require about one-and-a-half times as much lime as was found in association with it, indicating the probability that part of the nitrogen taken up as nitric acid was as the nitrate of some other base—potash, and possibly, to some extent, soda also.

Turning to the results with the rotation clover grown by the mixed manure, calculation shows that in the case of this continuously vegetating, unripened, and much higher nitrogen-yielding crop, there was very much more of both lime and carbonic acid in the ash for 100 of nitrogen assimilated than in the total bean crop. If, however, the whole of the nitrogen of the clover crops had been taken up as calcium nitrate, it would have required nearly twice as much lime as the amount found, provided the whole of it remained; nor would the amounts of potash and soda found suffice to make up the balance. Again, the amount of carbonic acid found is little more than two-thirds as much as would be required to represent organic acid equivalent to the amount of nitric acid subjected to change. Either, therefore, fixed base, partly in combination with organic acid, must have been eliminated from the above-ground parts of the plant and passed into the roots, and possibly into the soil, or a good deal of the nitrogen must have been taken up in some other form than as nitrate; possibly in part as organic nitrogen taken up from the soil by the agency of the acid sap, or in part as free nitrogen probably brought into combination under the influence of micro-organisms within the nodules found on the roots of leguminous plants, the resulting compound being either directly available as a source of nitrogen to the host, or it may be only after it has itself suffered change.

However this may be, considering the very characteristic differences in the mineral composition of the different crops of rotation according to the amounts of nitrogen they assimilate, the fact that undoubtedly the highly nitrogenous Leguminosæ do take up, at any rate, a large proportion of their nitrogen as nitrate, and that the greater the amount

of nitrogen assimilated the more is the ash characterized by containing fixed base, and especially lime. in combination with carbonic acid, it seems very probable, if not indeed established, that the office of the lime, and partly that of the other bases also, is that of carriers of nitric acid, which, when transformed and the nitrogen assimilated, leaves the base as a residue, presumably in combination with organic acid. Further, the power of these plants to assimilate so very much more nitrogen over a given area than the other crops may, at any rate in part, be dependent on their being able, by virtue of the range and character of their roots, to gather up more nitrogen in the form supposed than the plants with which they are alternated in rotation. Such a view does not, however, exclude the supposition that some of their nitrogen is derived in other ways, as above referred to.

In connection with the foregoing results of direct experimental investigation into the mineral composition of leguminous crops, it may be observed that clover at any rate, grows more favorably on land that has recently been chalked or limed; that chalking or liming of the mixed herbage of grass land also favors the development of the leguminous herbage; and that the application of gypsum to clover has been found very effective on some lands, especially in America, though it has not proved to be at all generally useful when it has been so applied in this country. Indeed, the direct application of potash as manure is certainly more frequent, and is more generally recognized as effective for leguminous crops than is that of lime, notwithstanding its obvious importance and its great influence on the luxuriance of growth of such crops. This may perhaps be partly explained by the facts that, in many if not in most soils, the immediately available supply of potash within the root range of the plant will probably be sooner exhausted than will that of lime.

SUMMARY AND GENERAL CONCLUSIONS.

I must, in conclusion, very briefly summarize the facts brought out in this extended inquiry on the subject of rotation, and endeavor to draw from them an explanation of the benefits arising from the practice of it.

At the commencement it was pointed out that although many different rotations are adopted, they may for the most part be considered as little more than local adaptations of the system of alternating root crops and leguminous crops with the cereals. Thus, there are rotations of five, six, seven, or more courses. But these variations are, for the most part, only adaptations of the principle to variations of soil, altitude, aspect, climate, markets, and other local conditions; and they consist chiefly in the variation in the description of the root crop, and perhaps the introduction of potatoes; in growing a different cereal, or it may be more than one cereal consecutively; in the growth of some other leguminous crop than clover; or the intermixture with the clover of grass seeds; and perhaps the extension of the period allotted to this element of the rotation to two or more years.

It is true also, that under any specific rotation there may be deviations from the plan of retaining the whole of the root crop, the straw of the grain crops, and the leguminous fodder crops, on the farm, for the production of meat or milk, and coincidently for that of manure to be returned to the land. But it is also true that, when under the influence of special local or other demand—proximity to towns, easy railway or other communication, and so on—the products which would otherwise be retained on the farm are exported from it; the import of town or other manures is generally an essential condition of such practice. Indeed, this system of free sale very frequently involves full compensation by purchased manures of some kind. In our own country such deviations from the practice of merely selling grain and meat have been much developed in recent years, and they will doubtless continue to increase under the altered conditions of our agriculture, dependent on very large imports of grain, increasing imports of meat and other products of feeding, and very large imports of cattle food and other agricultural produce. Already much more attention is being devoted to dairy products, not only on grass farms but on those that are mainly arable; and there will doubtless be some, but probably by no means so great an extension as some suppose, in the production of other smaller articles required by town populations.

It is further true, though the remark applies in a very limited degree to our own country, that there are other deviations which have more the character of exceptions to the general rule of rotation, such as the introduction of flax, hemp, tobacco, or other so-called industrial crops. But in these cases, as with potatoes, the growth involves special expenditure for manure, instead of conservation of it. Indeed the inducement is the high price of the product, rather than the maintenance or the improvement of the condition of the land for future crops.

Still, as such deviations from regular rotation practice as have been referred to do, as has been said, generally involve more or less, and frequently full compensation by manure from external sources, we may, in endeavoring to explain the benefits which may accrue from the practice of rotation, confine attention for the purposes of illustration to what may be called a self-supporting system, and to the simple four-course one which has been selected for investigation at Rothamsted, and from the results relating to which the illustrations which have been brought forward have been drawn.

It will be well first, briefly, to refer to the evidence relating to some of the more important mineral constituents found in the different crops of the four-course rotation.

Of phosphoric acid the cereal crops take up as much as, or more than, any of the other crops of the rotation excepting clover; and the greater portion of what they take up is lost to the farm in the salable product—the grain. The remainder, that in the straw, as well as that in the roots and the leguminous crops, is supposed to be retained on the farm, excepting the small amount exported in meat and milk.

Of potash each of the crops takes up very much more than of phosphoric acid. But much less potash than phosphoric acid is exported in the cereal grains, much more being retained in the straw, whilst the other products of the rotation, the roots and the Leguminosæ, which are also supposed to be retained on the farm, contain very much more potash than the cereals, and comparatively little of it is exported in meat and milk. The general result is that the whole of the crops of rotation take up very much more of potash than of phosphoric acid, while probably even less of it is eventually lost to the land.

Of lime very little is taken up by the cereal crops and by the roots, much less than of potash; more by the Leguminosæ than by the other crops, and by the clover especially, sometimes much more than by all the other crops of the rotation put together. Of the lime of the crops, however, very little goes in the salable products of the farm under the conditions supposed of a self-supporting rotation. There is, however, frequently a considerable loss of lime in land drainage.

Although the facts relating to other mineral constituents of the crops are not without significance, I must here refer to only one other of these constituents, namely, the silica.

The interpolated crops of rotation—the roots and the Leguminosæ—take up scarcely any silica; but the cereals take up a very large amount of it. Indeed, the large amount of silica taken up by these crops when grown under ordinary conditions is as characteristic a chemical phenomenon of rotation as is the very large amount of lime taken up by clover and other Leguminosæ. Very little silica, however, is lost to the land in the assumed salable products.

Thus, then, although different, and sometimes very large amounts of these typical mineral constituents are taken up by the various crops constituting the rotation, there is no material export of any in the salable products excepting of phosphoric acid and of potash; and, so far at least as phosphoric acid is concerned, experience has shown that it may be advantageously supplied in purchased manures.

But, although the eventual loss to the land of mineral constituents is, in a self-supporting rotation, comparatively so small, the very fact that the different crops require for their growth, not only very different amounts of individual constituents, but require these to be available within the soil in very different conditions, both of combination and of distribution, points to the conclusion that, in any explanation of the benefits of an alternation of crops, the position and the rôle of the mineral constituents must not be overlooked; and the less can it be so when their connection with the very important element—the nitrogen of the crops—is considered.

As to the nitrogen, it has been seen that, although very characteristically benefited by nitrogenous manures, the cereal crops take up and retain much less nitrogen than any of the crops alternated with them. In fact, the root crops may contain two or more times as much

nitrogen as either of the cereals, and the leguminous crop, especially the clover, much more than the root crops. The greater part of the nitrogen of the cereals is, however, sold off the farm; but perhaps not more than 10 or 15 per cent of that of either the root crop, or the clover, or other forage leguminous crop. Thus, most of the nitrogen of the straw of the cereals, and a very large proportion of that of the much more highly nitrogen-yielding crops, returns to the land as manure, for the benefit of future cereals and other crops. Indeed, it is, as a rule, only a comparatively small proportion of the very much increased amount of nitrogen obtained in rotation compared with that in continuous cereal cropping (chiefly due to the interpolated crops), that is lost to the land in the salable products.

As to the source of the nitrogen of the so-called "restorative crops," it has been shown that certainly in the case of the roots it is not, as has sometimes been assumed, that such plants take up nitrogen from the air by virtue of their extended leaf surface. Both common experience and direct experiment demonstrate that they are as dependent as any crop that is grown, on available nitrogen within the soil, which is generally supplied by the direct application of nitrogenous manures—natural or artificial. Under such conditions of supply, however, the root crops, so to speak, gross feeders as they are, and distributing a very large amount of fibrous-feeding root within the soil, avail themselves of a much greater quantity of the nitrogen supplied than the cereals would do under similar circumstances; this result being partly due to their period of accumulation and growth, extending even months after the period of collection by the ripening cereals has terminated, and at the season when nitrification within the soil is the most active, and the accumulation of nitrates in it is the greatest. Lastly, full supply of both mineral constituents and nitrogen being at command, these crops assimilate a very large amount of carbon from the atmosphere, and produce, besides nitrogenous food products, a very large amount of the carbohydrate—sugar, as respiratory and fat-forming food for the live stock of the farm.

Very much the same may be said of maize as grown as a fodder crop in America, as of roots as grown in rotation in other countries. Thus, there can be no doubt that the maize derives its nitrogen from the soil, collecting some time longer than wheat, and availing itself of the nitrates formed after the collection by the wheat has ceased. But so far as the product is consumed on the farm, much of its nitrogen is recovered in the manure, the more when the food is used for growing or fattening stock, and the less when for the production of milk.

The still more highly nitrogenous leguminous crops on the other hand, although not characteristically benefited by nitrogenous manures, nevertheless contribute much more nitrogen to the total produce of the rotation than any of the other crops comprised in it. It is also certain that, at any rate a large proportion of the nitrogen of these crops is

obtained from the soil and subsoil; though recent investigations have proved that some of their nitrogen, and sometimes much of it, may be derived indirectly from the free nitrogen of the atmosphere, brought into combination under the influence of micro-organisms within the nodules on the roots of the plants.

It is the leguminous fodder crops, and among them especially clover, which has a much more extended period of growth, and much more extended range of collection within the soil and subsoil than any of the other crops of the rotation, that yield in their produce the largest amount of nitrogen per acre. Much of this is doubtless taken up as nitrate, yet the direct application of nitrate of soda has comparatively little beneficial influence on their growth. The nitric acid is probably taken up chiefly as nitrate of lime, but probably as nitrate of potash also; and it is not without significance that the high nitrogen-yielding clover takes up, or at least retains, very little soda. The general result is, then, that although undoubtedly the clover takes up a good deal of nitrogen as nitrate, this would seem to be derived from accumulations within the soil, which are brought into suitable conditions of combination, and distributed through a wide range of soil and subsoil.

So much then for the benefits of rotation, so far as the requirements, the habits of growth, and the capabilities of gathering and assimilating the various mineral constituents and the nitrogen of the different crops are concerned. It can not be doubted that the difference in the amounts, in the conditions of combination, and in the distribution within the soil of the various mineral constituents is at least an element in the explanation of the benefits of alternation; nor, on the other hand, can there be any doubt that the facts relating to the amount and to the sources of the nitrogen of the different crops are of still greater significance than are those in regard to the mineral constituents.

But it is not only the conditions of growth, but the uses of the different crops when grown, that have to be taken into account. Thus, the cereals when grown in rotation yield more produce for sale in the season of growth than when grown continuously. Again, the crops alternated with them accumulate very much more mineral constituents and of nitrogen in their produce than do the cereals themselves, and by far the greater proportion of those constituents remains in circulation in the manure of the farm, whilst the remainder yields highly valuable products for sale in the forms of meat and milk.

Further, independently of the benefits arising from the difference in the requirements and results of growth of the different crops, of the increased amount of manure available, and of the increased sale of highly valuable animal products there are other elements of advantage of considerable importance. For example, with a variety of crops the mechanical operations of the farm, involving horse and hand labor, are better distributed over the year, and are therefore more economically

performed. Lastly, but by no means least, the opportunities which alternate cropping afford for the cleaning of the land from weeds is a prominent element of advantage.

Thus, then, the benefits of rotation are very various; and the explanation of them, though largely dependent on the facts which have been ascertained by scientific investigation, also largely involves considerations connected with the general economy of the farm; and since, as has been seen, so large a proportion of the produce grown is retained on the farm, as stock food or litter, it is obvious that the benefits can not be fully appreciated without arriving at some definite idea of the importance to the farmer of the salable animal products and of the manure obtained. This subject will be considered in the next section.

SECTION VI.

THE FEEDING OF ANIMALS FOR THE PRODUCTION OF MEAT, MILK, AND MANURE, AND FOR THE EXERCISE OF FORCE.

INTRODUCTION AND HISTORY.

It was shown in the last section (V) on the rotation of crops that any explanation of the benefits of rotation is quite inadequate which does not take into account the results of the feeding of animals on the farm. Thus, in the discussion of the amounts of the produce of the various crops grown in alternation with one another, and of the amounts of the various constituents of the individual crops, or of their separate parts, it was pointed out that only certain portions of them were at once available as salable products; a large proportion remaining for use on the farm in some way, and only eventually yielding a profitable return.

The extent to which the retention on the farm of the constituents accumulated in the crops may take place may usefully be illustrated by reference to a particular example, which will convey a clearer conception of the importance of the subject than any mere general statement can do. Accordingly, in Table 66 is given an approximate estimate of the proportion of certain selected constituents of the crops grown in the typical four-course rotation of Swedish turnips, barley, leguminous crop, and wheat, which will be at once sold off the farm, and of the amounts retained upon it; supposing that only the grain of the cereals is sold, and that the root crop, the leguminous crop, and the straw of the cereals are retained for further use. The estimates are founded on the average amounts of produce obtained over eight courses in the fully manured rotation, the particulars of which were given and discussed in the section on rotation above referred to.

TABLE 66.—*Illustration of the proportion of the constituents of crops grown in rotation at once sold off the farm, and of those retained upon it for further use.*

	Per cent of total in the crops.	
	At once sold off the farm.	Retained on the farm for further use.
	Per cent.	*Per cent.*
Dry matter	30.6	69.4
Nitrogen	43.4	56.6
Total mineral matter (ash)	14.5	85.5
Phosphoric acid	56.2	43.8
Potash	20	80

It is true that the exact figures given in the table have only reference to a particular case, and that in practice there will sometimes be larger and sometimes smaller proportions of these constituents of the crops at once sold or retained on the farm. Nevertheless, the illustrations may be taken as essentially typical, and as so far conveying a very useful impression on the subject.

Referring to the figures, the question arises, To what beneficial or profitable purposes are about two-thirds of the total vegetable substance grown—more than half its nitrogen, nearly half its phosphoric acid, and about four-fifths of its potash—retained on the farm? Briefly stated, it is for the feeding of animals for the production of meat, milk, and manure, and for the exercise of force, that is, for their labor. It is, then, the facts and the principles involved in the feeding of the animals of the farm for these various purposes that we have now to consider.

It is obvious that so long as a country is only sparsely populated, and the needs of the people are amply supplied under a comparatively rude system of agriculture, in which extended area precludes the necessity for improved methods, there would be little, either of scope or of inducement, to study economy in the feeding of animals or to systematic practice in regard to it. But as population increases in proportion to area, there arises the necessity for increased production over a given area. It has already been pointed out in section V on rotation that, in our own country, gradually a greater variety of crops came to be grown; that first leguminous crops and then root crops were introduced, and finally the system of rotation became general. Thus, a much greater variety and a much greater quantity of home-produced stock foods became available, and in time foods of various kinds were imported from other countries.

Somewhat similar changes in their food resources occurred in various parts of the continent of Europe; and, with these, came the inducement, if not the necessity, to pay more attention to the subject of feeding. The end was, however, sought to be attained by somewhat characteristically different methods in our own country and on the continent. With us, more special attention was paid to the improvement of the breeds of the farm animals themselves, not only to enhance the development of the most valuable characters in the final product, but to secure early maturity, and thus materially to economize the expenditure of food in the mere maintenance of the living meat-and-manure-making machine. As to the use and adaptation of different foods, but little systematic inquiry was undertaken in regard to it, each feeder relying largely on his own judgment, or on the unwritten rules adopted in his locality as the result of practical experience.

On the Continent, however, and especially in Germany, much more attention was paid to the character of the food than to that of the animal, and toward the end of the last century and the beginning of this much was devoted to determining the comparative values of different

foods, and tables were constructed in which, adopting hay as the standard, it was attempted to arrange all other foods according to their supposed value compared with that standard. The plan was to give the amount of each food which it was estimated was equivalent in food-value to 100 parts of hay.

The first comprehensive tables of "hay values" were constructed by Thaer, and were published by him in 1809. His operations, experiments, and writings were of an essentially practical character. His estimates of so-called "hay values" seem, however, to have been based to some extent on the determinations of the supposed nutritive contents of different foods which had been made by Einhof, but partly, also, on his own determinations, and partly on direct feeding experiments. In these he sought to ascertain how much of the respective foods was required to substitute a given quantity of hay in the daily ration of the animals. His estimates were, at any rate, controlled by such experiments, and he states that their results, upon the whole, tended to confirm the conclusions arrived at by analysis.

Other writers also published tables of hay values, or hay equivalents of foods. In some of these the results of new experiments, sometimes analytical and sometimes practical, were embodied; but it is obvious from the identity of the figures in many cases that they were largely compilations, one from another.

Such was the condition of knowledge on the subject when Boussingault commenced his investigation of it, soon after 1830. Like Thaer, Boussingault had the advantage of being a practical agriculturist, but while Thaer looked at the question of the feeding of the animals of the farm almost exclusively from the practical point of view, Boussingault approached it mainly from that of the chemist and the physiologist; though he, at the same time, made direct experiments with farm animals, and so arranged and conducted them as not only to elucidate some points of special scientific interest, but also to afford data which might serve both for the explanation and for the improvement of agricultural practice.

Thus, besides contributing much toward a better knowledge of the actual and comparative value of different foods, he investigated the question whether animals either availed themselves of the free nitrogen of the air as a source of some of their nitrogen, or eliminated either free or combined nitrogen by the lungs or skin; also whether the fat stored up by the fattening animal was exclusively derived from the already formed fat of the food, or whether it was produced within the body, from other constituents of the food.

From the point of view of the practical agriculturist, Boussingault seems fully to have assumed the utility of attempting to arrange stock foods according to their nutritive value compared with that of hay as a standard; and, in fact, this idea has given a direction to much subsequent investigation also.

The first great advance made by Boussingault was, however, to determine the nitrogen in a large number of different foods; and taking the amount of it as for the time the best measure of nutritive value, on this basis to compare them with hay. That is to say—supposing 100 parts of average good hay to contain a certain amount of nitrogen, how much of each of the other foods would be required to supply the same amount of it. These amounts would, on the supposition adopted, represent the quantities by weight in which one food may be substituted for another, and they may be considered as the theoretical equivalents of 100 of hay. Accordingly he determined the nitrogen in about seventy-six different descriptions of food, which at that date involved a truly enormous amount of labor.

Further, he selected a few typical articles of food for comparative feeding experiments, so as to be able to compare the results obtained both with those indicated by theory according to their contents of nitrogen, and with the estimates of others founded chiefly on somewhat similar practical trials. He fully recognized the difficulties and uncertainties of such modes of experimenting and took great care to obviate error arising from them. He discussed the general results of some experiments with milking cows, but gave in some detail the particulars and results of ten experiments with the horse. The normal food being hay, straw, and oats, he in one case substituted half the hay by potatoes, in another by Jerusalem artichokes, in another by mangels, in another by ruta-baga, and in another by carrots. Again, in another the straw and oats were replaced by potatoes; in another half the hay was replaced by more oats and straw, and so on. In each case he noted the change in weight and condition of the animals in other respects, if any; and he judged accordingly whether the amount of the food given in substitution was too much or too little, and whether, therefore, the practical or the theoretical results were the most to be relied upon.

He brought together in a table[1] the estimates of the value compared with 100 of hay of the seventy-six different articles of food according to the amount of nitrogen he found in them; and side by side he gave the hay value of the foods according to the published estimates of others, and to the results of his own practical trials.

Subsequently, however, Boussingault was not satisfied with his results so obtained, and he pointed out that what was still wanting was the determination of the amount of the various nonnitrogenous constituents also, and of how much of them was digestible, and how much indigestible; and eventually he determined in ninety different food stuffs, not only the nitrogen, but the mineral matter, the woody fiber or cellulose, the fatty matter, and (probably by difference) the remaining non-nitrogenous matters, which he recorded as starch, sugar, and allied bodies. As to the nitrogen, he still, as formerly, multiplies the amount found by 6.25 to represent albumin, legumin, or casein.

[1] Rural Economy, etc. (English edition), 1845. H. Bailliere, London.

He also still took 100 parts of hay as the standard by which to compare the nutritive value of other foods; as for ruminants and horses he considered it a good standard food, and that the relation in it of the nitrogenous and the digestible nonnitrogenous constituents was fairly normal. He now, however, modifies the meaning of the equivalent arrived at by taking into account the amount of digestible nonnitrogenous substance associated with the standard amount of nitrogen in each case; and, if there were a deficiency, he states how much of some food rich in digestible nonnitrogenous matters should be added to complete the equivalent, and so make it comparable with the 100 of hay. Indeed, he now laid it down that equivalent rations must contain equal amounts of digestible nonnitrogenous, as well as of the nitrogenous bodies.

In the case of the ninety descriptions of food which he analyzed as above referred to, he gives a table[1] recording the results obtained and then shows the amount of each food required to contribute the same quantity of nitrogenous substance as 100 of hay. Next he calculated how much nutritive nonnitrogenous matter, reckoned as carbohydrate of 42 per cent carbon, was supplied in the amount of each food containing the nitrogen of 100 of hay. If the amount were less than in 100 of hay he calculated how much straw was required to supply the deficiency, assuming straw to contain 45 per cent of such matter. The final result shows not only the same amount of nitrogenous, but as much of digestible nonnitrogenous subtances also as 100 of hay. If, however, the nitrogen equivalent of the food contained an excess of digestible nonnitrogenous constituents he did not make any corresponding deduction from the ration.

Boussingault fully recognized that food equivalents so calculated are only satisfactory in comparing foods of the same description, which he classifies generally as follows: (1) Hays and straws, (2) roots and tubers, (3) oily seeds, (4) cereal grains, leguminous seeds, oil cakes, etc. He pointed out that when the application of the tables is thus limited they are very useful in showing how one food may be advantageously substituted for another of the same class, according to relative abundance cheapness, and so on.

In conclusion, in regard to Boussingault, in giving a sketch of the history of the progress in our knowledge of the subject of the feeding of the animals of the farm it was only due to him to give prominence to his enormous, painstaking, and most conscientious labors in regard to it. This is the case, independently of any direct applicability of his results and conclusions at the present time, because he was essentially the pioneer, and his conceptions and methods have had a very marked influence on the direction of subsequent investigations.

It was in 1842, that is after Boussingault's first systematic discussion of the subject, but before his second, that Liebig published his work

[1] Économie Rurale, Deuxième edition, 1851, vol. 2, pp. 356–363. Paris.

entitled "Chemistry in its Applications to Physiology and Pathology." In it he treated of food in its relations to the various exigencies of the animal body, and, apparently impressed, as was Boussingault, with the fact that nitrogenous constituents were both essential and characteristic of the animal body, and that they must, therefore, be supplied in the food they consumed, and in the case of the Herbivora in vegetable food stuffs, he also, like Boussingault, indeed probably directly influenced by his results and conclusions, himself concluded that the comparative values of food stuffs, as such, were, as a rule, measurable by their richness in the nitrogenous, rather than in that of the nonnitrogenous constituents—that is to say, more by their flesh-forming than by their more specially respiratory or fat-forming capacities. Thus he says (p. 45):

Chemical researches have shown that all such parts of vegetables as can afford nutriment to animals contain certain constituents which are rich in nitrogen, and the most ordinary experience proves that animals require for their support and nutrition less of these parts of plants in proportion as they abound in the nitrogenous constituents.

Again, at page 369 of the third edition of his Chemical Letters (1851), he says:

The admirable experiments of Boussingault prove that the increase in the weight of the body, in the fattening or feeding of stock (just as is the case with the supply of milk obtained from milch cows), is in proportion to the amount of plastic constituents in the daily supply of fodder.

Liebig would probably be somewhat biased in favor of the conclusion here stated by the view he held, that the amount of force exercised in the animal body was measurable by the amount of nitrogenous substance transformed, and this again by the amount of urea found in the urine. To Liebig's views on this latter point, as well as on the question of the sources in the food of the fat of the animal body, and on some other points of scientific, as well as practical interest, I shall have to refer further when considering each of these several questions independently. In the meantime, my special object is to show what were the prevailing opinions on the subject of the adaptation of foods according to their composition, to the sum of the requirements of the animals of the farm, which include not only those for the mere maintenance of the body, but those for increase in live weight, for the production of milk, or for the exercise of force, as the case may be. It was, however, not only in regard to the foods of the animals of the farm, but to human foods also, that the system of estimating their comparative value according to their percentage of nitrogen came to be applied. Thus, different descriptions of flour and bread, and numerous other aliments, both vegetable and animal, were examined, and their comparative food values were assumed to be indicated by their richness in nitrogen.

THE ROTHAMSTED FEEDING EXPERIMENTS.

It was in 1847, after Boussingault had published his first table of the comparative nutritive value of different foods, founded on their percent-

age of nitrogen, and after Liebig had substantially indorsed Boussingault's conclusions on the point, that systematic feeding experiments were commenced at Rothamsted. In the arrangement of them, the settlement of the questions raised by the experiments and conclusions of Boussingault, and by the enunciation of the theoretical views of Liebig, was kept prominently in view. But the plans adopted were, in some points, characteristically different from those adopted by Boussingault, and even more so from those which, as we shall see further on, have been generally followed by subsequent experimenters.

In Boussingault's feeding experiments he sought to ascertain the comparative values of different foods by trials with animals which were, as far as possible, maintained in a uniform condition, both as to weight and other circumstances, but which were, nevertheless, living and feeding under the normal conditions of such animals; for example, a cow yielding milk, or a horse performing work. A vast amount of careful experiment has, however, since been devoted by others to determine the food requirements of a given live weight for mere sustenance or maintenance, that is, not only without either loss or gain, but exclusively of the yield of milk, increase in live weight, or the exercise of force; and then, as a separate question, to determine in the case of animals feeding for the production of meat, how much of the different constituents of food is required to be supplemented to the mere sustenance ration, to obtain the maximum increase for the minimum expenditure of the different food constituents.

Our own plan was, on the other hand, in the case of animals fed for the production of meat, to select foods of recognized value for such animals; to give a fixed quantity daily, of one or more, and to allow the animals to take ad libitum of some other or complementary food; the object being, excepting in certain cases for comparison, to secure that they should yield normal or full increase in weight, and that the results should indicate to what constituent, or class of constituents, in the food, the actual and comparative results were to be attributed.

It will be seen that, under such a plan, the animals practically fixed their own consumption according to the composition of the foods and to their requirements, and that the amounts of food, or of its various constituents consumed, covered the requirements, both for mere maintenance, and for the growth and fattening increase, as the case might be. It was thought that results so obtained, being comparable with those of actual practice, would supply important data for the elucidation of the principles involved in such practice.

Several hundred animals, oxen, sheep, and pigs, have been experimented upon. In the greater number of cases, and especially in the earlier years, it was, owing to the amount of labor involved, found to be impracticable to do more in the way of analysis of the foods than to determine in them the percentages of dry substance, of mineral matter, of nitrogen, and sometimes of fatty matter. From the results

were calculated the amounts of total nitrogenous substance, of total nonnitrogenous organic substance, and of total organic matter which the foods supplied.

At that time little or nothing had been done in the way of determining either the condition of combination of the nitrogen in vegetable foods or the character of the nonnitrogenous bodies. The only method then practicable was to calculate the amount of nitrogenous substances from the amount of nitrogen, a plan which we pointed out was liable seriously to mislead, if due allowance were not made for differences in the composition and condition of the substances so estimated. In the case of ripened final products, such as cereal grains and the leguminous seeds, there is comparatively little error in so reckoning the whole of the nitrogen to exist as albuminoid bodies. In hays and straws there is a much larger proportion of the total nitrogen nonalbuminoid, and in succulent products, such as roots and tubers, much more still.

Then, again, the proportion of the nonnitrogenous organic substance which is digestible is very different in different vegetable products. Thus, in hays and straws there is a large proportion of indigestible woody fiber; in cereal grains and leguminous seeds much less, and in roots and tubers very little.

We shall, nevertheless, find that when, as was always done in our interpretation of the results, due reservation is made as to the character both of the so reckoned nitrogenous and of the nonnitrogenous organic substance of the different foods, the indications are very clear and significant as to whether, taking our fattening food stuffs as they go, their comparative food value is measurable more by their contents in digestible nitrogenous or in digestible nonnitrogenous constituents.

The investigation also involved the determination of the composition and especially of the amounts and the proportion of the nitrogenous and of the nonnitrogenous constituents in the bodies of the animals themselves and in their increase while fattening, and it also involved that of the composition of the excrements, that is, of the manure.

Thus, the inquiry embraced the following points:

(1) The amount of food and of its several constituents consumed in relation to a given live weight of animal within a given time.

(2) The amount of food and of its several constituents consumed to produce a given amount of increase in live weight.

(3) The proportion and relative development of the different organs or parts of different animals.

(4) The proximate and ultimate composition of the animals in different conditions as to age and fatness, and the probable composition of their increase in live weight during the fattening process.

(5) The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed.

(6) The loss or expenditure of constituents by respiration and the

cutaneous exhalations; that is, in the mere sustenance of the living meat-and-manure-making machine.

(7) The yield of milk in relation to the food consumed to produce it, and the influence of different descriptions of food on the quantity and on the composition of the milk.

As already said, several hundred animals—oxen, sheep, and pigs—have been submitted to experiment.

The amount and the relative development of the different organs or parts were determined in 2 calves, 2 heifers, 14 bullocks, 1 lamb, 249 sheep, and 59 pigs.

The percentages of water, mineral matter, fat, and nitrogenous substance were determined in certain separated parts, and in the entire bodies of ten animals, namely, 1 calf, 2 oxen, 1 lamb, 4 sheep, and 2 pigs. Complete analyses of the ashes, respectively, of the entire carcasses of the mixed internal and other "offal" parts, and of the entire bodies of each of these ten animals have also been made.

From the data provided, as above described, as to the chemical composition of the different descriptions of animal in different conditions as to age and fatness, the composition of the increase while fattening, and the relation of the constituents stored up in the increase to those consumed in food have been estimated.

To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs have been experimented upon.

The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly; that is, by means of a respiration apparatus, but only by difference; that is, by calculation, founded on the amounts of dry matter, ash, and nitrogen in the food, in the (increase) feces, and urine.

Independently of the points of inquiry above enumerated, the results obtained have supplied data for the consideration of the following questions: (1) The sources in the food of the fat produced in the animal body; (2) the characteristic demands of the animal body (for nitrogenous or nonnitrogenous constituents of food) in the exercise of muscular power; (3) the comparative characters of animal and vegetable foods in human dietaries.

FOOD CONSUMED AND INCREASE PRODUCED.

I propose first to consider the results illustrating the amounts of food and of its nitrogenous and nonnitrogenous constituents, respectively, consumed by a given live weight of animal within a given time, and the amounts required to produce a given amount of increase in live weight. The illustrations will be drawn from experiments with sheep and with pigs.

THE EXPERIMENTS WITH SHEEP.

Table 67 shows, for each of three series of experiments with sheep, in the first three columns the amounts of nitrogenous, of nonnitrog-

enous, and of total organic substance consumed per 100 pounds live weight per week, and in the last three columns the amounts consumed to produce 100 pounds increase in live weight. The figures represent the quantities of the crude constituents consumed; that is, the amounts of nitrogenous substance calculated by multiplying the nitrogen by 6.3, which implies that the whole of it exists in the foods as albuminoids, which admittedly is not the case. It will be seen, however, that this method is quite sufficient for the purposes of the illustrations at present in view, though it is frequently far from accurate in the case of unripened vegetable products, and it is especially so in that of succulent foods, such as feeding roots. The amounts of crude nonnitrogenous substance are calculated by deducting those of the mineral matter and of the crude nitrogenous constituents from those of the total dry matter consumed. Here, again, it is admitted that the results are only approximations to the truth, but it will be seen that, as in the case of the nitrogenous constituents, they are nevertheless quite sufficient for the purposes of our present illustrations. The crude total organic matter is simply the sum of the nitrogenous and nonnitrogenous, calculated as above.

TABLE 67.—*Experiments with sheep, made at Rothamsted in 1850 (nitrogenous and nonnitrogenous constituents consumed per 100 pounds live weight per week, and to produce 100 pounds increase in live weight).*

SERIES 1.—FIVE SHEEP IN EACH PEN (FOURTEEN WEEKS).

Pens.	Limited food.	Ad libitum food.	Per 100 pounds live weight per week.			To produce 100 pounds increase in live weight.		
			Nitrogenous.	Nonnitrogenous.	Total organic.	Nitrogenous.	Nonnitrogenous.	Total organic.
1	Linseed cake	Swedish turnips	2.46	9.85	12.31	167	650	817
2	Oats		1.57	11.36	12.93	103	684	787
3	Clover chaff		1.64	13.12	14.76	102	736	838
4	Oat straw chaff		1.07	10.17	11.24	102	913	1,015
	Mean		1.68	11.13	12.81	118	746	864

SERIES 2.—FIVE SHEEP IN EACH PEN (NINETEEN WEEKS).

Pens.	Limited food.	Ad libitum food.	Nitrogenous.	Nonnitrogenous.	Total organic.	Nitrogenous.	Nonnitrogenous.	Total organic.
1	Linseed cake	Clover chaff	3.78	12.93	16.71	321	1,103	1,424
2	Linseed		3.21	12.66	15.87	289	1,144	1,433
3	Barley		2.58	13.79	16.37	235	1,269	1,504
4	Malt		2.52	14.02	16.55	266	1,457	1,723
	Mean		3.02	13.35	16.38	278	1,244	1,521

SERIES 3.—FIVE[1] SHEEP IN EACH PEN (TEN WEEKS).

Pens.	Limited food.	Ad libitum food.	Nitrogenous.	Nonnitrogenous.	Total organic.	Nitrogenous.	Nonnitrogenous.	Total organic.
1	Barley	Mangels	1.70	10.59	12.29	118	731	850
2	Malt and malt dust		1.64	10.12	11.76	111	677	788
3	Barley (steeped)		2.08	12.60	14.68	121	730	851
4	Malt and dust (steeped)		1.77	10.70	12.47	136	821	958
5	Malt and dust (extra quantity)		1.89	11.63	13.52	126	776	903
	Mean		1.82	11.13	12.94	123	747	870

[1] Only 4 sheep in pens 1, 3, and 4.

Referring to the results, it is impossible to go into any detail here. A glance at the figures in the first three columns of the table (67), relating to the amounts of the constituents consumed per 100 pounds live weight per week, is sufficient to show that, in all comparable cases, there was much more uniformity in the amounts of the nonnitrogenous than in those of the nitrogenous substance consumed for a given live weight of the fattening animal within a given time. The deviations from this general regularity in the amount of nonnitrogenous substance consumed are, indeed, in most cases, such that when they are examined they tend clearly to show that the uniformity would be considerably greater if the amounts of only the really available respiratory and fat-forming constituents had been represented, instead of those of the crude or total nonnitrogenous substance consumed.

In reading the figures, allowance has obviously to be made, both for those of the nonnitrogenous constituents which would probably become at once effete, and also for the different respiratory and fat-forming capacities of the portions which are digestible. Thus, comparing series with series, the amounts are higher in series 2, where the ad libitum food was clover chaff containing a large amount of indigestible fiber, than in either of the other series, where it consisted of Swedish turnips or mangel-wurzel. Then, the quantity consumed was higher in the third pen of series 1, with clover chaff, than in the other pens of the same series; and it was lower in pen 1 of series 1, with linseed cake containing much oil, and it was again lower in pens 1 and 2 of series 2, also with much fatty matter in the food, than in the other pens of the same series with cereal grain.

Indeed, when we bear in mind the various circumstances which must tend to modify the indications of the actual figures, it will be admitted that the coincidences in the amounts of available respiratory and fat-forming constituents consumed by a given weight of animal within a given time are much more striking and conclusive than, considering the views prevalent on the subject at the time, could have been anticipated.

With this general uniformity in the amounts of the nonnitrogenous substance consumed by a given live weight within a given time, the amounts of the nitrogenous constituents so consumed are, on the other hand, seen to vary under the same circumstances in the proportion of from 1 to 2, or 3, or more.

Let us now refer to the last three columns of the table (67), which show the amounts of the respective constituents consumed to produce 100 pounds increase in live weight. In considering these results we must, as when discussing those relating to the consumption by a given live weight within a given time, read the indications of the actual figures as modified by the obviously different capacities for the purposes of the animal economy, of the substances, the amounts of which they are assumed to represent. It must also be borne in mind that the

proportion of real dry substance in the increase of the animal will vary to some extent according to the character of the food. For example, it will be rather the less, the more succulent the food, and the greater, the greater the proportion of fat in the increase. Again, as in the case of the results showing the consumption for a given live weight of the fattening animal within a given time, the figures represented the demand, not only for respiration and for maintenance in other respects, but also that for increase in live weight, so now those specially arranged to show the relation of consumption to increase at the same time include the amounts required by the exigencies of respiration and maintenance.

Taking a general view of the results, which is all that can be done here, it is seen that where clover chaff, with its large amount of indigestible woody fiber was used as the ad libitum food, the total amount of nonnitrogenous substance consumed to produce a given increase in live weight was much greater than where the ad libitum food consisted of roots. Due allowance must, therefore, be made for this in comparing the results of one series with those of another. Doing this, it is obvious that the amounts of really available nonnitrogenous substance consumed were at any rate much more nearly uniform in the different series and in the different pens than were those of the nitrogenous substance. Of the differences that would still remain most would be again reduced by making allowance for the different respiratory and fat-forming capacities of the remaining available nonnitrogenous constituents, since, for example, much less of fatty matter would be required than of starch or sugar, or of the pectine compounds of the roots.

Again, as in the case of the consumption by a given live weight within a given time, so now in that of the consumption to produce a given amount of increase there is a much wider range of difference in the amounts of the nitrogenous than of the nonnitrogenous constituents consumed; and the differences are, as before, much greater than can be explained by the differences in the character of the nitrogenous substances which the figures represent in the different cases.

Thus, then, the results of these experiments with sheep, when interpreted with due regard to the known differences in the character of the nitrogenous and nonnitrogenous constituents in the different foods, fully justify the conclusions drawn from them more than forty years ago, namely, that taking food stuffs as they go, it is their supply of the digestible nonnitrogenous, that is, of the more specially respiratory and fat-forming constituents, rather than that of the nitrogenous or specially flesh-forming ones, that regulates both the amount of food consumed by a given live weight of animal within a given time and the amount of increase in live weight produced.

But as it seems to have been tacitly assumed in recent years, since much attention has been paid to the investigation of the digestibility of the different constituents of foods, that conclusions founded on the

determined amounts in the foods of the crude substances only can not be relied upon, we have had the whole of our early results, both with sheep and with pigs, recalculated, making correction, as far as practicable, for the amounts of the constituents in the different foods which are assumed to be indigestible or otherwise not of food value, according to the tables given by Emil von Wolff in the edition of his work published in 1888. He there gives for nearly two hundred different articles of stock foods the percentages of water, mineral matter (ash), crude protein, crude fiber, nonnitrogenous extractive matters, and crude fat, and then the percentages of digestible albuminoids, digestible carbohydrates, and digestible fat. In applying his data to our results, the amount of the crude substance in each description of food is reduced in the proportion which his figures show of crude to digestible in the same description of food. Further, in the case of the so estimated amounts of digestible fatty matter, the figure obtained has been multiplied by 2.4 to bring it approximately to its equivalent of carbohydrate, the amount then being added to the other digestible nonnitrogenous substance, so reckoning the whole as carbohydrate. Lastly, as Wolff makes no correction for the nonalbuminoid condition of a large portion of the nitrogen in succulent roots, it has been assumed, in accordance with results obtained at Rothamsted and elsewhere, that in Swedish turnips only 45 per cent and in mangels only 40 per cent of the total nitrogen will exist as albuminoids.

There are obvious objections to some of the modes adopted for the determination of the digestible constituents of the various foods which render them inapplicable, without considerable reservation, to the estimate of the amounts of the constituents which will probably be actually digested in the case of ordinary liberal rations. But, if accepted as approximations only, they undoubtedly afford useful data for some general conclusions.

Neither space nor time will permit of either the record or the discussion of the recalculated tables. It must suffice here to say that the results are so recalculated, that is, making correction as far as present knowledge permits for the probable amounts of the indigestible or nonavailable constituents of the various foods, not only fully confirm the conclusions drawn on a careful study of the circumstances of the experiments and of their results more than forty years ago, but they bring out the points then maintained still more clearly to view.

THE EXPERIMENTS WITH PIGS.

Let us next see whether experiments with pigs lead to similar conclusions. The pig requires much less bulk in his food than the ruminant. His food, and especially his fattening food, consists, weight for weight, of a much larger proportion of digestible or convertible constituents, and contains very little effete woody fiber. Thus, while the food of oxen and sheep is composed principally of grass, hay, straw, and roots,

with a comparatively small proportion of grain, leguminous seeds, or other concentrated foods, that of the pig consists largely of grain or other seeds, which contain a comparatively small amount of indigestible woody fiber, and a large proportion of starch or other digestible carbohydrate and nitrogenous matters which are almost entirely in the condition of albuminoids. It is true that the pig consumes also more or less of starchy tubers or saccharine roots, which contain a considerable proportion of their nitrogen in other forms than albuminoids. But the more rapidly he is fattened the larger is the proportion in his food of starchy grains or other ripened seeds.

Notwithstanding the much more concentrated and digestible character of the food of the fattening pig, he consumes a much larger quantity of dry substance in proportion to his weight than either the ox or the sheep. Under these circumstances he yields much more increase, both in proportion to a given live weight within a given time, and to a given amount of dry substance of food consumed. This is clearly illustrated in Table 69 (p. 258), which shows as an approximate average that per 100 pounds live weight per week the fattening ox will consume about 12.5 pounds of dry substance of food and yield 1.13 pounds of increase; the sheep will consume about 16 pounds of dry substance of food and yield 1.76 pounds of increase; while the pig, on the other hand, will consume about 27 pounds of dry substance of his more concentrated food and yield about 6.43 pounds of increase. Indeed, compared with oxen or sheep, the liberally fed fattening pig will consume much more food in excess of that required for the respiratory function and for mere maintenance, so that the amounts of nonnitrogenous matters consumed for a given live weight within a given time represent in less proportion the respiratory requirements, and in a greater proportion those for increase.

Numerous feeding experiments have been made at Rothamsted with pigs. In 1850, series 1, with 12 pens; series 2, also comprising 12 pens, and series 3, with 5 pens, and subsequently a fourth series of 4 pens was made. The general plan was to give, in one or more pens, food of high or of low percentage of nitrogen, as the case might be, ad libitum; then in others to give a fixed and limited amount of food of low percentage of nitrogen, and, ad libitum, a food of high percentage; or a fixed and limited amount of food of high percentage of nitrogen, and, ad libitum, a food of low percentage, and so on; and as the ad libitum food always supplied much the larger proportion of the total ration, the animals fixed their own consumption, according to the composition of the foods and to their own requirements, including those both for respiration and maintenance, and for increase.

The foods of high percentage of nitrogen consisted in most cases of an equal mixture of bean and lentil meal, that is, of highly nitrogenous leguminous seeds; and those of low percentage were, in most cases, either maize meal or barley meal. In some, however, either pure starch

or pure sugar was given. The details of the foods, the weights, and increase of the animals, and of the amounts of the various foods and of their nitrogenous and nonnitrogenous constituents consumed per 100 pounds live weight per week, and to produce 100 pounds of increase in live weight, have been given and fully discussed in various papers.[1]

The conclusion drawn from the results of the various experiments with pigs was that, in their case, as in that with sheep, it was the supplies in the food of the available nonnitrogenous, or total organic, constituents, rather than those of the available nitrogenous substance, that regulated the amount consumed, both by a given live weight within a given time, and to produce a given amount of increase. The point is, however, even more clearly brought to view by the graphic representation of the results given in the colored diagrams facing page 316.

In explanation of them it may be stated that nitrogenous substance is represented by black, nonnitrogenous by yellow, and total organic substance by red. The upper diagram (I) illustrates the relative amounts of the respective constituents consumed per 100 pounds live weight per week, and the lower one (II) the amounts consumed to produce 100 pounds increase in live weight. Each of the thirty columns represents the results of a separate experiment or pen.

The first nine columns show the results of experiments 1 to 8 and 12, of series 1; the next twelve those of the twelve experiments of series 2; the next five those of the five experiments of series 3; and the last four those of the four experiments of series 4. It may be added that there were three pigs in each pen of series 1, 2, and 4, and four in each pen of series 3.

The plan of the diagrams in other respects will be best understood by giving an example. Take, for instance, the amounts of nitrogenous substance consumed per 100 pounds live weight per week, as represented in black in the left-hand division of Diagram I. The lowest amount so consumed throughout the thirty experiments was in pen 5, and that amount is taken as 100, and as the standard by which to compare the amounts consumed in the other pens, and it will be seen that in the case of this pen 5 the coloring does not extend above the base line, which is numbered 100 in the column of figures given at each side of the diagram. It will be further seen that the figures range up to 300, and that, for example, in the case of pen 1 the black coloring extends above the 300 line; that is to say, there were more than 300 parts of nitrogenous substance consumed in that pen, against only 100 in pen 5. In like manner the height of the coloring for each of the other pens represents the proportion of nitrogenous substance consumed in that pen compared with the amount in pen 5 taken as 100.

Exactly the same plan is adopted in representing the relative

[1] On the Composition of Foods in relation to Respiration and the Feeding of Animals (Rept. Brit. Assoc. for 1852); Pig Feeding (Jour. Roy. Agl. Soc. Eng., 14 (1853), p. 459).

amounts of nonnitrogenous and of total organic substance consumed in the different pens. Thus, the lowest amount of nonnitrogenous substance consumed per 100 pounds live weight per week was in pen 10, which is therefore represented as 100, and the relative amounts consumed in the other pens are represented by the different heights of the yellow coloring above the 100 base line.

Again, of total organic substance consumed per 100 pounds live weight per week, the lowest amount was in pen 23, and the greater amount so consumed in each of the other pens is represented by the height above the base line of the red coloring in each case.

It need only be added that precisely the same plan is followed in the construction of Diagram II, which shows the relative amounts of the substances consumed in the different experiments to produce 100 pounds increase in live weight.

Referring to the results, and first to those represented in Diagram I, which shows the relative amounts consumed per 100 pounds live weight per week, a glance brings strikingly to view the fact that there was no uniformity whatever in the amounts of nitrogenous substance so consumed in the thirty different cases, representing as many different rations. Indeed, it is seen that the amounts ranged in the proportion of 100 to more than 300, with very great variation between these amounts. The range in the nonnitrogenous substance so consumed is, on the other hand, very much less, reaching, in but few cases, from 100 to 150. Lastly, in the case of the total organic substance the range is less still.

Next, referring to Diagram II, showing the relative amounts of the different constituents consumed to produce 100 pounds increase in live weight, there is again no uniformity in the amounts of nitrogenous substance so consumed. There is, however, great uniformity in the amounts of the nonnitrogenous substance consumed; and there is, in the majority of cases, about the same uniformity in those of the total organic substance consumed.

It should be understood that in these diagrams relating to pigs as in the table relating to the experiments with sheep it is the amounts of the crude nitrogenous, the crude nonnitrogenous, and the crude total organic substance as determined by the methods of analysis already described, and which were the only ones practicable at the time, that are represented. Of course, therefore, the indications of the actual results have, as in the case of those with sheep, to be interpreted with due regard to the known facts in each case. But, to meet objection, we, nearly twenty years ago, recalculated the results and reconstructed the diagrams, making correction for indigestible or nonavailable constituents in the various foods, in accordance with the then published tables of Prof. Emil von Wolff, and more recently, as in the case of the experiments with sheep, we have had them again recalculated according to his more recent tables, already referred to.

It may be stated that the diagrams, as first reconstructed, entirely confirmed the conclusions previously drawn; and, indeed, illustrated the points brought out by those at first, and now again given even more strikingly still; that is, they showed a wider range in the amounts of the nitrogeneous substance consumed in the different experiments, with one or two easily explained exceptions, a less variation in the amounts of the nonnitrogenous substance, and especially a less range in the amounts of total organic substance consumed. The two methods showed, moreover, with some obviously necessary exceptions, comparatively little difference in what is called the "nutritive ratio;" that is, the relation of the nonnitrogenous to the nitrogenous constituents. As it is impossible on this occasion to give and discuss both sets of results, it seems best, after this explanation, to adhere to the originally obtained and recorded results which led to the conclusions arrived at so long ago, rather than to adopt corrections based upon factors as yet not sufficiently established. Nevertheless, it is satisfactory to find that, applying the best methods of correction which subsequent investigations suggest, the conclusions formerly drawn are confirmed and emphasized, rather than in anyway vitiated or modified.

In conclusion, in regard to this branch of the subject, it must be considered established that, taking ordinary food stuffs as they go, neither the amount consumed in relation to a given live weight of the animal within a given time (which, of course, in the fattening animal covers the requirements for increase as well as for sustenance), nor the amount consumed to yield a given amount of increase in live weight (which covers the requirements for sustenance also) was at all in proportion to the amount of the nitrogenous constituents supplied. It is, on the other hand, obvious that the consumption, both for sustenance and for increase, was much more nearly in proportion to the amount of the digestible and available nonnitrogenous constituents supplied, but that it was more nearly still regulated by the amount of the total digestible organic substance—nitrogenous and nonnitrogenous together—which the foods supplied. The indication is, indeed, as will be more clearly seen further on, that if there be a deficiency of available nonnitrogenous constituents, an excess of the nitrogenous may to a certain extent take the place of the nonnitrogenous; that, in fact, within certain limits, the two classes of constituents may, for the purposes of respiration and fat formation, mutually replace each other.

When the character of the main products of respiration and the prominence, in a quantitative sense, of the respiratory function in the maintenance of the body are considered, it seems only what might be expected, that the consumption by a given live weight of animal within a given time should be regulated more by the supplies in the food of the oxidable nonnitrogenous than of the nitrogenous or more specially flesh-forming constituents; and now that it is known, as I shall further on have to show is the case, that in the exercise of force the

respiratory action is enormously increased, while that of nitrogenous transformation is but little augmented, the result is rendered still more consistent and intelligible.

That the increase in live weight of the animal should (provided the food be not abnormally poor in nitrogenous substances) also be regulated more by the supplies of the nonnitrogenous than of the nitrogenous or flesh-forming constituents, does not at first sight seem so intelligible.

There is, however, no doubt of the fact that our current fattening rations are, as such, more valuable in proportion to their richness in digestible and available nonnitrogenous than to that of their nitrogenous constituents. At the same time, as the manure is valuable largely in proportion to the nitrogen it contains, there is, so far, an advantage in giving a food rich in nitrogen, provided it is in other respects a good one, and, weight for weight, not much more costly. But since in recent years the vegetable products most benefited by nitrogenous manures have been so largely imported as much to reduce the value of the home-grown crops, even this advantage of highly nitrogenous food stuffs is becoming of less importance, and that of having the best food for the progress of the animal one of more and more consideration.

The question obviously suggests itself, Of what does the increase of the animal chiefly consist? To experimental evidence on this point I propose next to direct attention.

COMPOSITION OF OXEN, SHEEP, AND PIGS, AND OF THEIR INCREASE WHILE FATTENING.

I propose to show the composition of some of the animals of the farm in different conditions as to age and fatness; to estimate the probable composition of their increase in live weight during the fattening process; and to show the relation of the constituents stored up in the increase to those consumed in the food. The results which have been obtained will also afford data for the discussion of the question of the sources in the food of the fat produced in the animal body; they will further supply evidence as to the composition of the manure in relation to that of the food consumed; and lastly they will lead to a consideration of the characteristic food requirements of the body in the exercise of force.

To determine the ultimate composition, and in a sense the proximate composition also, of oxen, sheep, and pigs, and under such conditions that the results obtained should serve as data for the estimation of the probable composition of their increase while growing and fattening, 10 animals were selected for analysis, namely: a fat calf, a half-fat ox, and a fat ox; a fat lamb, a store sheep, a half-fat old sheep, a fat sheep, and an extra-fat sheep; a store pig, and a fat pig.

Table 68 (p. 249) shows the percentages of mineral matter, of nitrogenous compounds, of fat, of total dry substance, and of water, in the upper division in the collective carcass parts, in the middle division

in the collective offal parts (excluding contents of stomachs and intestines), and in the lower division in the entire bodies of the 10 animals. The weight of the contents of stomachs and intestines is also given.

TABLE 68.—*Percentage composition of the carcasses, the offal, and the entire bodies of ten animals of different descriptions, or in different conditions of maturity.*

Description of animal.	Mineral matter (ash).	Nitrogenous substance.	Fat.	Total dry substance.	Water.	Contents of stomachs and intestines (in moist state).
Carcass:						
Fat calf	4.48	16.6	16.6	37.7	62.3	....
Half-fat ox	5.56	17.8	22.6	46	54	....
Fat ox	4.56	15	34.8	54.4	45.6	....
Fat lamb	3.63	10.9	36.9	51.4	48.6	....
Store sheep	4.36	14.5	23.8	42.7	57.3	....
Half-fat old sheep	4.13	14.9	31.3	50.3	49.7	....
Fat sheep	3.45	11.5	45.4	60.3	39.7	....
Extra-fat sheep	2.77	9.1	55.1	67	33	....
Store pig	2.57	14	28.1	44.7	55.3	....
Fat pig	1.40	10.5	49.5	61.4	38.6	....
Means of all	3.69	13.5	34.4	51.6	48.4	....
Offal (excluding contents of stomachs and intestines):						
Fat calf	3.41	17.1	14.6	35.1	64.9	....
Half-fat ox	4.05	20.6	15.7	40.4	59.6	....
Fat ox	3.40	17.5	26.3	47.2	52.8	....
Fat lamb	2.45	18.9	20.1	41.5	58.5	....
Store sheep	2.19	18	16.1	36.3	63.7	....
Half-fat old sheep	2.72	17.7	18.5	38.9	61.1	....
Fat sheep	2.32	16.1	26.4	44.8	55.2	....
Extra-fat sheep	3.64	16.8	34.5	54.9	45.1	....
Store pig	3.07	14	15	32.1	67.9	....
Fat pig	2.97	14.8	22.8	40.6	59.4	....
Means of all	3.02	17.2	21	41.2	58.8	....
Entire animal (fasted live weight):						
Fat calf	3.80	15.2	14.8	33.8	63	3.17
Half-fat ox	4.66	16.6	19.1	40.3	51.5	8.19
Fat ox	3.92	14.5	30.1	48.5	45.5	5.98
Fat lamb	2.94	12.3	28.5	43.7	47.8	8.54
Store sheep	3.16	14.8	18.7	36.7	57.3	6
Half-fat old sheep	3.17	14	23.5	40.7	50.2	9.05
Fat sheep	2.81	12.2	35.6	50.6	43.4	6.02
Extra-fat sheep	2.90	10.9	45.8	59.6	35.2	5.18
Store pig	2.67	13.7	23.3	39.7	55.1	5.22
Fat pig	1.65	10.9	42.2	54.7	41.3	3.97
Means of all	3.17	13.5	28.2	44.9	49	6.13

It may in the first place be observed that, comparing one animal with another, all the results tend to show a prominent connection between the amount of total mineral matter and that of the nitrogenous constituents of the body; there being a general tendency to a rise or fall in the percentage of mineral matter with the rise or fall in that of the nitrogenous compounds.

Comparing the composition of the different carcasses, it is seen that there was, in every instance excepting that of the calf, a considerably higher percentage of fat than of total nitrogenous substance.

In the carcass of even the store or lean sheep there was more than one-and-a-half times as much fat as nitrogenous substance, and in that of the store or lean pig there was twice as much. In the carcass of the half-fat ox there was one-fourth more fat than nitrogenous matter, and in that of half-fat old sheep there was more than twice as much.

Of the fatter animals, those assumed to be in a suitable condition for sale as human food, the carcass of the fat ox contained two and one-third times as much, that of the fat sheep four times, and that of the very fat sheep even six times as much fat as nitrogenous substance. Lastly, in the carcass of the moderately fat pig, there was nearly five times as much fat as nitrogenous compounds.

Turning now to the second division of Table 68 (p. 249) which shows the composition of the collective offal parts (excluding contents of stomachs and intestines), the figures do not show such an uniform tendency to a diminution in the percentage of mineral matter coincidently with that of the nitrogenous substance as the animal matures, as was observed in the case of the carcasses. This, however, is doubtless due to the fact that the ash of the offal parts includes adventitious matter adhering to the pelt, hair, or wool which it was impossible entirely to remove.

It is seen that the percentage of nitrogenous substance is in every case greater, and that of the fat very much less, in the collective offal than in the collective carcass parts. In the case of oxen and sheep, a large amount of the nitrogenous substance of the offal is in the non-consumable portions, the pelt, hair or wool, and hoofs; while some of the remainder is in the stomachs and intestines, which are only very partially consumed, and the rest in other parts which are more generally consumed, namely: the head flesh, with tongue and brains, the heart, the liver, the pancreas, the spleen, the diaphragm, and sometimes the lungs.

Lastly, in regard to the composition of the collective offal parts, it is seen that they contain a higher percentage of nitrogenous substance, a lower percentage of fat, and a lower percentage of total dry substance, and, consequently a larger proportion of water than the collective carcass parts.

It is obviously a matter of interest both from a dietetic point of view and as showing what proportion of the gross product of the feeding process is salable as human food, to consider what proportion of the fat and of the nitrogenous substance of the slaughtered animals, will, on the average, be consumed as human food in one form or another. The result of much inquiry leads to the conclusion that in our own country, on the average, the whole of the carcass fat and about one-fifth of the offal fat of oxen will be consumed; that of sheep, an amount equal to the whole of their carcass fat will be consumed; and that of the pig, an amount equal to the whole of its carcass fat and, in addition, more or less of its offal fat, will be sold and consumed as food.

Calculation leads to the conclusion that about one-sixth of the whole of the nitrogenous matter of the collective offal parts of oxen will, on the average, be consumed, but that the whole of the nitrogenous matter reclaimed as food from the offal parts will fall short of the amount contained in the bones of the carcass. So nearly, however, will these

quantities balance one another, especially if a portion of the gelatin from the carcass bones be consumed, that it may be assumed that, of the total nitrogenous substance of the bodies of these animals, only about as much as, or very little more than, is represented by the total amount in the carcasses, will be consumed. In the case of pigs, however, a larger proportion of the total nitrogenous substance of the body will be consumed than in that of the other animals; but, as the table shows, the percentage of total nitrogenous substance is less and that of the fat much greater in the pig than in the other animals.

Upon the whole, therefore, it would seem that the proportion of the consumed fat to the consumed nitrogenous substance will, on the average, be greater than its proportion in the total carcasses of the fattened animals. Such is pretty certainly the case in our own country, but the relations are admittedly far otherwise in the United States, and it is, to say the least, very questionable whether the difference is to the advantage of the consumers in that country.

Let us now turn to the lower division of Table 68 (p. 249) showing the composition of the entire bodies of the animals, which, of course, represents the gross product of the feeding process. It is this, therefore, that is of most interest to the farmer to consider in connection with the composition of the food expended in its production.

As was the case in the carcasses, there is also in the entire bodies a marked diminution in the percentage of mineral matter as the animal matures. Judging from the results of the analyses of the ashes of the animal bodies, it may be stated in general terms that about, or rather more than 40 per cent of the total mineral matter of the animals is phosphoric acid. In the case of oxen and sheep nearly 45 per cent, and in that of pigs about 40 per cent, will be lime, while of potash, the ash of oxen and sheep will probably contain from 5 to 6 per cent, and that of pigs 7 to 8 per cent, or more.

Of total nitrogenous compounds, as well as of total mineral matter, oxen seem to contain, in parallel conditions, a rather higher percentage than sheep, and sheep rather more than pigs. It is seen that the entire body of the fat calf contained about 15¼, that of a moderately fat ox 14½, of a fat lamb 12⅓, of a fat sheep 12¼, of a very fat one about 11, and of a moderately fattened pig also about 11 per cent of nitrogenous substance. The store or lean animals contained from 2 to 3 per cent more than moderately fat ones.

The figures show, on the other hand, that fat constitutes by far the largest item in the dry or solid matter of the entire bodies of the animals, especially of those fit for slaughtering as human food. Even the half-fat ox contained about 19 per cent of fat, or more than of nitrogenous substance. The entire body of the store sheep also contained nearly 19 per cent of fat, that is several per cent more than of nitrogenous substance; that of the half-fat old sheep 23½ per cent, or more than one and one-half times as much as of nitrogenous substance; and that

of the store pig also more than 23 per cent of fat, and about one and two-thirds times as much as of nitrogenous substance.

Of the fattened animals, the entire body of the fat ox contained rather more, and that of the fat lamb rather less, than 30 per cent of fat; that of the fat sheep 35½ per cent, of the very fat sheep 45¾ per cent, and that of the fat pig about 42 per cent of fat. The fat calf, however, contained even rather less than 15 per cent of fat.

Thus, the entire bodies, even of store or lean animals, may contain more fat than nitrogenous compounds, while those of fattened animals may contain several times as much. That of the fat ox contained more than twice as much, that of the moderately fat sheep nearly three times, of the very fat sheep more than four times, and of the moderately fattened pig about four times as much fat as nitrogenous substance.

In conclusion on this point, all the experimental evidence concurs in showing that the so-called "fattening" of animals is properly so designated. During the feeding or fattening process, the percentage of the total dry substance of the body is considerably increased; and the fatty matter accumulates in much larger proportion than the nitrogenous substance. It is evident, therefore, that the increase of the fattening animal must contain a lower percentage of nitrogenous substance and a higher percentage of both fat and total dry substance, than the entire body of the animal.

It is obvious, however, that the results of the analyses of the 10 animals do not supply data directly applicable for the estimation of the composition of animals in the very various conditions in which they are dealt with in practice, or of their increase over any given period under varying conditions of feeding. Accordingly, we have constructed tables founded on the analytical results above referred to, showing the probable average percentage composition of the different descriptions of animal, each at eight gradationary points from the store to the very fat condition; and the factors thus obtained have been applied for the calculation of the composition of the increase in a number of cases of ordinary practice, or of direct experiment in which the weights of the animals at the commencement and at the conclusion of a fixed period, the general character of the food they consumed, and their final condition were more or less fully known. It is admitted that these eight conditions do not cover all the variations of composition occurring in actual practice; but at the same time there can be no doubt that by the aid of such factors the feeder would be enabled to calculate with sufficient approximation to the truth for all practical purposes, the composition of the store animals he buys or sells, and of the fat ones he sells. At any rate I believe that the results are the best that existing knowledge enables us to provide.

It is impossible to go into any detail here, either as to the composition of the animals at the different stages or to the estimated composition of their increase, but the results may be briefly summarized as follows:

In the case of oxen the figures representing the composition of the animals at different stages of progress show that the percentage of mineral matter ranged from 5.15 in the store to only 3.43 in the very fat condition; that of the nitrogenous substance from 18 in the store to only 13.1 in the very fat state; and that of the fat increased from 11.7 in the store to 37.4 in the very fat condition. Again, the percentage of total dry substance increases from only 34.8 in the store to 54 in the very fat condition. Lastly, the percentage of water decreases from the store to the very fat condition.

The parallel results for sheep show that the percentage of mineral matter ranges from 3.25 in the store to only 2.90 in the very fat animal; the nitrogenous compounds from 15.5 per cent in the store to only 10.9 per cent in the very fat condition, and against these reductions the fat increases from 14.5 per cent in the store to 45.8 per cent in the very fat condition; and the total dry substance from 33.2 per cent to 59.6 per cent. There is, therefore, a lower percentage of total dry substance in the store sheep than in the store ox, owing to the less amount of mineral and nitrogenous matter in the store sheep. There is, on the other hand, a higher percentage of dry substance in the very fat sheep than in the very fat ox, owing to the higher percentage of fat in the sheep. Lastly, in the sheep the percentage of water diminishes from the earliest to the latest stage from 60.8 to only 35.2.

The results relating to the composition of pigs showed a reduction in the percentage of mineral matter from 2.93 in the store to only 1.14 in the very fat condition, and a reduction in that of nitrogenous substance from 14.4 in the store to 9.5 in the very fat state. But, instead of a reduction, there is an increase in the percentage of fat from 18.6 in the store to 51.6, or to more than half the weight of the body, in the very fat condition; and there is an increase in the percentage of total dry substance from 35.9 in the store to 62.2 in the very fat condition, and (excluding contents of stomachs, etc.) a reduction in the percentage of water from 58.6 to 34.4.

It may be observed that in no case do the percentages of total dry substance and of water make up 100; the difference being represented by the contents of stomachs and intestines, the amounts of which found in the animals actually analyzed are taken as the basis of the estimates for the amounts in the other conditions, just as in the case of the other constituents of the body.

I will next summarize very briefly the results of the application of these data as to the composition of the animals in different conditions for the purpose of estimating the composition of their increase, in passing from one condition to another.

First, referring to oxen, the composition of their increase during the feeding process has been estimated in the case of the recorded results of actual practical feeding, in some cases of large numbers of animals, and over considerable periods of time. Other cases have been those

of results obtained at Rothamsted or under Rothamsted superintendence, mostly in direct feeding experiments, but sometimes in the feeding of animals in the ordinary practice of the farm.

Reviewing the whole of the results, the indication was that the composition of the increase of moderately fattened oxen during a final fattening period of several months will contain about, or a little more than, $1\frac{1}{2}$ per cent of mineral matter; seldom more than 7 to 8 per cent of nitrogenous substance; and seldom as little as 60 and generally near 65 per cent of fat; whilst the total dry substance of the increase will generally range from 70 to 75 per cent. In the case, however, of oxen fattened very young, and the feeding period extending over a much longer time, similar calculations lead to the conclusion that the growing and fattening increase of such animals may contain perhaps $2\frac{1}{4}$ per cent, or more, of mineral matter, against only about $1\frac{1}{2}$ per cent over a limited final period of more purely fattening increase; about 10 per cent of nitrogenous substance against only 7 to 8 per cent in the only fattening increase; and perhaps only from 50 to 55 per cent of fat against from 60 to 65 per cent in the more exclusively fattening increase. In fact, while the growing and fattening increase would consist of about two-thirds dry substance and one-third water, that of the more purely fattening increase would consist of nearly three-fourths dry substance and only about one-fourth water.

Similar results relating to sheep lead to the conclusion that during a final period of some months of feeding on good fattening food their increase will generally contain not less than 2 per cent of mineral matter, and frequently more, that is, distinctly more than in the case of oxen, the quantity largely depending on the amount of wool. Of nitrogenous substance, the final fattening increase of sheep will probably seldom contain more than 7 per cent and frequently somewhat less. In other words, notwithstanding the large amount of nitrogen in the wool of sheep, their fattening increase will probably generally contain less nitrogenous substance than that of oxen. On the other hand, the increase of well fed and moderately fattened sheep will generally contain nearly and sometimes more than 70 per cent of fat against an average of less than 65 per cent in the case of oxen; and in the case of very fat sheep the percentage of fat in the increase may even reach 75 per cent.

Upon the whole it may be assumed that the increase of liberally fed and moderately fattened sheep over several months of final fattening will probably consist of about 2 per cent of mineral matter, about or less than 7 per cent of nitrogenous substance, from 65 to 70 per cent of fat; and in all, of from 75 to 80 per cent of total dry substance; while the increase over the final period of excessive fattening may contain from 70 to 75 per cent of fat and from 80 to 85 per cent of total dry substance.

Referring to pigs, the increase of those liberally and suitably fed for

fresh pork will probably on the average contain an immaterial amount of mineral matter, only from 6½ to 7½ per cent of nitrogenous substance, from 65 to 70 per cent of fat, and from 70 to 75 per cent of total dry substance. The increase over the last few months of high feeding of pigs fed for curing will, however, probably contain lower percentages of nitrogenous substance, but higher and sometimes considerably higher percentages of both fat and total dry substance. The tendency of the demand in recent years has, however, been for less excessively fat bacon than formerly.

Thus far, then, it has been shown that the amounts of food, or of its various constituents consumed, both for a given live weight of animal within a given time and to produce a given amount of increase, were very much more dependent on the quantities of the nonnitrogenous than on those of the nitrogenous constituents which the food supplied. It has been said that when the large requirement for nonnitrogenous constituents of food to meet the expenditure by respiration is borne in mind, it need not excite surprise that consumption in relation to a given live weight within a given time should be so largely measureable by the amount of digestible and available nonnitrogenous substance which the food supplies; but that, at first sight, it was less intelligible that the quantities consumed to produce a given amount of increase in live weight should also be much more dependent on the supplies of the nonnitrogenous than on those of the nitrogenous constituents of the food.

The results relating to the chemical composition of the different animals, in different conditions as to age and maturity, have shown, however, that even store animals may contain as much, or even more, of the nonnitrogenous substance (fat) than of nitrogenous substance, while the bodies of fattened animals may contain two, three, four, or even more times as much dry fat as dry nitrogenous matter. It has further been shown that the proportion of fat to nitrogenous substance in the increase in live weight of the fattening animal is much higher than in the entire bodies of the fattened animals. If, therefore, the nonnitrogenous substance of the increase (the fat) is derived from the nonnitrogenous constituents of the food, the relatively large demand for such constituents for the production of fattening increase would seem to be amply accounted for.

The important question arises, therefore, what are the sources in the food of the fat of the fattening animal? In other words, from what constituent or constituents in the food is the fat produced?

SOURCES IN THE FOOD OF THE FAT PRODUCED IN THE ANIMAL BODY.

Prior to the publication of Liebig's work on "Organic Chemistry in its Application to Physiology and Pathology," in 1842, it seems to have been assumed that the Herbivora derived their fat from ready-formed fatty matters in their food, and that the Carnivora derived theirs from

the ready-formed fat of the animals they consumed. Liebig argued that, as a rule, the food consumed by the Herbivora did not contain sufficient fatty matter for the purpose, and he maintained that although fat might be formed from the nitrogenous substance of the food, its main source was the starch, sugar, and other carbohydrates, which the food supplied.

Dumas and Boussingault[1] at first called in question the view that fat was produced in the animal body, and assumed that the food of the Herbivora supplied sufficient fatty matter to account for the whole of the fat stored up. Subsequently, however, Dumas and Milne-Edwards,[2] from the results of experiments with bees; Persoz,[3] from experiments with geese, and Boussingault[4] from those with pigs, geese, and ducks, concluded that fat was formed from the carbohydrates of the food. At the same time Boussingault considered that, in normal feeding, the amount of albuminoids consumed would generally supply sufficient carbon for the production of the fat formed by the animal.

Next came the evidence of the Rothamsted experiments, the majority of which were conducted within the years 1848–1853, inclusive; and they involved feeding experiments on between 400 and 500 animals, with foods of known composition; the slaughter, determination of the weights of the parts, and noting on the character as to fatness, etc., of more than 300 animals; and finally, the chemical analysis of 10 animals.

In the first place, it was clearly demonstrated that much more fat was stored up in the bodies of the fattening animals than could be derived from the ready-formed fatty matter in their food. Secondly, from a careful study of the enormous amount of experimental data obtained, as well as of the known facts of practical experience in feeding, it was considered that no doubt whatever could be entertained that much, if not the whole, of the fat formed in the bodies of the Herbivora fed for the production of meat was derived from the carbohydrates of the food.

In fact, the experimentally determined relation of the nonnitrogenous and of the nitrogenous constituents of the food, respectively, to the amount of increase produced; the composition of fattening increase generally; the relatively greater tendency to grow in frame and to form flesh with highly nitrogenous food; the greater tendency to form fat with food comparatively rich in nonnitrogenous substances, and especially in carbohydrates; and common experience in feeding—all pointed in the same direction.

For some years there was little or no discussion on the subject; and it seemed to be tacitly admitted, both on the Continent and in this

[1] Balance of Organic Nature, 1844, p. 116 et seq.

[2] Compt. Rend., Vol. XVII, p. 531.

[3] Ann. Chim. Phys., Vol. XIV, p. 408 et seq.

[4] Ibid., Vol. XIV, p. 419 et seq.; Vol. XVIII, p. 444 et seq.

country, that the views of Liebig as to the formation of at any rate much of the fat of the Herbivora from carbohydrates were correct.

In 1865, however, at a meeting of a congress of agricultural chemists, held at Munich in August of that year, Professor Voit, from the results of experiments made in Pettenkofer's respiration apparatus, with dogs, fed chiefly on flesh, maintained that fat must have been produced from nitrogenous substance; and that this was probably the chief, if not the only, source of the fat even of Herbivora. Pettenkofer and Voit further maintained that to establish the formation of fat from the carbohydrates, experiments must be brought forward in which the fat deposited was in excess of that supplied by the food, plus that which could be derived from the transformation of albumin.

Of course, the mere fact that the food consumed contained enough nitrogenous substance for the formation of all the fat that had been produced would of itself be no proof that that substance had been its exclusive source. On the other hand, if the amount of fat stored up in the animal was in excess of that which could be derived from the ready-formed fatty matter of the food, and from the transformation of the nitrogenous substance, it would be proved that at any rate some of the stored-up fat must have had another source, and this could only be the carbohydrates.

Accordingly, the results of many of the Rothamsted feeding experiments were calculated, to ascertain whether or not the ready-formed fat and the nitrogenous substance of the food were sufficient to account for the whole of the fat estimated to have been stored up. None of the experiments had been specially arranged with a view to the elucidation of this question. In some of them, however, what may be called minimum amounts, and in others excessive quantities, of nitrogenous substance had been consumed. Some of the results seemed to us to afford clear evidence on the point, and we gave a paper on the subject in the physiological section, at the meeting of the British Association for the Advancement of Science, at Nottingham, in 1866; and it was published, in abstract, in the report of the British association for 1866, and in full in the Philosophical Magazine for December of that year. And, as it is upon the results as then given that any subsequent discussion of our conclusion has been founded, I propose in the first place to consider the evidence afforded by those results, but afterwards to adduce certain modifications of some of them, in order to bring them more into accord with recent knowledge on some points, and to meet more effectively objections that have been raised against the conclusion drawn from them.

The first point to consider was, What description of animal is likely to yield the most direct and conclusive results on the subject? Obviously the one which is fed more especially with the view to the production of fat; which consumes in its most appropriate fattening food a comparatively low proportion of nitrogenous substance, and a

comparatively high proportion of carbohydrates; and which yields a large proportion of fat, both in relation to the weight of its body within a given time, and to the amount of food consumed. The following table (69) briefly summarizes the results of very numerous experiments with oxen, sheep, and pigs, so far as they illustrate the comparative characters of the different descriptions of animal in regard to the points above enumerated:

TABLE 69.—*Showing the comparative fattening quantities of different animals.*

	Oxen.	Sheep.	Pigs.
Average of relation of parts in 100 live weight	16	249	59
Stomach and contents	11.5	7.4	1.3
Intestines and contents	2.8	3.5	6.2
	14.3	10.9	7.5
Internal loose fat	4.6	7	1.6
Heart, aorta, lungs, windpipe, liver, gall bladder and contents, pancreas, spleen, and blood	.7	7.3	6.6
Other offal parts	13	15	1.1
Total offal parts	38.9	40.2	16.8
Carcass	59.3	59.7	82.6
Loss by evaporation, etc	1.8	.1	.6
Total	100	100	100
Per 100 live weight:			
Dry substance consumed in food per week	12.5	16	27
Increase yielded per week	1.13	1.76	6.43
Per 100 dry substance of food:			
Fat in increase	5.2	7	15.7
Total dry substance in increase	6.2	8	17.6
Total dry substance in excretions	36.5	31.9	16.7
Average fat per cent:			
In lean condition	16	18	22
In fat condition	30	33	44
In increase while fattening	60	65	70

In the first place, it is to be observed that although the proportion of intestines and contents is greater, that of the stomach and contents is very much less in the pig than in either of the ruminants, as also is that of the stomachs and contents, and intestines and contents taken together, the percentage of these collectively being in oxen 14.3, in sheep 10.9, and in pigs only 7.5 of the weight of the body. The fact is, that the appropriate fattening food of the pig consists of ripened seeds and highly starchy roots, containing but little indigestible fiber, whilst that of the ruminants contains a considerable amount of slowly digestible or indigestible cellulose, and often a much greater amount of indigestible or unassimilable nitrogenous substance. The result is, that a less proportion of the live weight of the pig consists of more or less effete matter retained in the alimentary organs.

Then, the second division of the table shows, that with the much higher character of its food and the much less proportion of it indigestible and effete, the pig both consumes very much more and yields very much more increase for a given live weight within a given time.

Lastly, as is shown in the third division of the table, for 100 of dry substance of food consumed the pig yields very much more, both of fat and of dry substance in increase; and, on the other hand, voids very much less of dry substance in urine and in feces.

Thus, as compared with either oxen or sheep, the pig offers many advantages as a subject for the consideration of the relations of food and increase, and consequently for that of the source in the food of the fat which he yields. He has a less proportion of alimentary organs and contents, he consumes more food in proportion to his weight, he yields a larger proportion both of total increase and of fat; and finally, much less of his food is effete and voided. The general result is, that changes in his live weight are in a much less proportion influenced by variations in the contents of the alimentary organs, and are, therefore, much truer indications of change in the substance of the body; and hence the range of error in calculating the amount and composition of his increase, in relation to the amount and composition of the food consumed, is much less.

THE EXPERIMENTS AT ROTHAMSTED WITH PIGS.

In the selection of the experiments with pigs for calculating whether more fat was stored up than could possibly have been derived from the ready-formed fat and the nitrogenous substance of the food, some have been taken in which the proportion of the nitrogenous to the nonnitrogenous constituents of the food was abnormally high, and others in which it was fairly normal, or even low. In all cases the experiments were conducted for periods of not less than eight or ten weeks, and the amounts, both of total increase and of fat stored up, were so large in proportion both to the original weight of the animal and to the amount of food consumed that the data obtained may safely be relied upon for the settlement of the question at issue.

In the upper portion of Table 70 (p. 260) are recorded some particulars of the nine experiments selected for calculation, namely: The description of the food, the number of animals experimented upon, the duration of the experiment, the original and final live weights, the increase per head and on 100 original weight, the percentage of carcass in fasted live weight, and the amount of crude nonnitrogenous to 1 of crude nitrogenous substance in the food.

The middle division of the table shows for 100 increase in live weight the amount of nitrogenous substance consumed in the food, the amount of it estimated to be stored up in the increase, and the quantity remaining and therefore possibly available for the formation of fat. Next, there is given the estimated amount of fat in the increase, the amount ready formed in the food, and the difference, that is, the amount newly formed. There are then given the amounts of carbon in the estimated newly-formed fat, the amounts in the available nitrogenous substance minus that in the urea formed, supposing the whole of the nitrogen not stored up in increase to contribute to such formation; and lastly, the difference, that is, the amount of carbon available from the nitrogenous substance for the formation of fat more or less than that required for the amount of fat produced.

Then, in the bottom division of the table are shown for 100 of carbon in the estimated produced fat the amount available from the nitrogenous substance, and the amount not available from that source, in each experiment; the amount not so available representing, of course, the proportion required from other sources.

TABLE 70.—*Relation of the total fat in the increase to the ready-formed fatty matter in the food, and of the carbon in the fat produced within the body to that in the nitrogenous substance consumed, in experiments with fattening pigs.*

Experiments	1.	2.	3.	4.	5.	6.	7.	8.	9.
	Bean meal, lentil meal, and bran, each 1 part; barley meal, 3 parts.	Bean meal, lentil meal, bran, and maize meal, each, ad libitum.	Mixture (equal parts) bran and lentil meal, ad libitum.	Maize meal, ad libitum.	Barley meal, ad libitum.	3 pounds 3 ounces lentil meal and 9 ounces bran per head per day, and—			Lentil meal, bran, sugar, and starch, each ad libitum.
						Sugar, ad libitum.	Starch, ad libitum.	Sugar and starch, each ad libitum.	
Conditions and actual results of experiments.									
Number of animals	1	3	3	3	3	3	3	3	3
Duration of experiment, weeks	10	8	8	8	8	10	10	10	10
Original live weight per head ... pounds	103	143	147	144	149	95	95	94	97
Final live weight per head, pounds	191	228	248	217	246	178	178	184	201
Increase in live weight per head ... pounds	88	85	101	73	97	83	83	90	104
Increase on 100 original weight	85.4	59.7	68.9	51.3	64.9	86.4	87	96.8	106.8
Per cent carcass in live weight	82.8	83.9	81.9	85.4	....	83.1	80.1	81.7	80.8
Nonnitrogenous substance to 1 of nitrogenous substance in food (crude)	3.6	3.3	2	6.6	6	4.1	4.1	4.7	3.9
Per 100 increase in live weight.									
Nitrogenous substance:									
In food	100	107	138	57	64	81	81	74	82
In increase	7.8	6.1	6.7	5.3	6.5	7.5	7.6	8	8.2
Available for fat formation	92.2	100.9	131.3	51.7	57.5	73.5	73.4	66	73.8
Fat:									
In increase	63.1	73.9	69.6	79	71.2	64.1	63.9	62	59.9
In food	15.6	20.4	11.2	26.3	12.4	7.9	7.9	7.3	6.6
Newly formed	47.5	53.5	58.4	52.7	58.8	56.2	56	54.7	53.3
Carbon:									
In newly-formed fat	36.6	41.2	45	40.6	45.3	43.3	43.1	42.1	41
In available nitrogenous substance minus urea	44	48.1	62.6	24.7	27.4	35.1	35	31.5	35.2
More (+) or less (—) in nitrogenous substance than required	+7.4	+6.9	+17.6	—15.9	—17.9	—8.2	—8.1	—10.6	—5.8
Per 100 carbon in estimated newly-formed fat.									
Carbon:									
In available nitrogenous substance minus urea	120.2	116.7	139.1	60.8	60.5	81.1	81.2	74.8	85.9
Not available from nitrogenous substance	....	....	....	39.2	39.5	18.9	18.8	25.2	14.1

It is hardly necessary to point out that, according to the above mode of illustration, the figures show not only the utmost proportion of the stored-up fat which could possibly have had its source in the nitrogenous substance of the food, but notably more than could possibly have been so derived. Thus, to say nothing of other considerations, it has been assumed, for simplicity of illustration, and for the sake of argument, that the whole of the nitrogenous substance of the food not stored up as increase would be perfectly digested and be available for fat formation, and that, in the breaking up of the nitrogenous substance for the formation of fat, no other carbon compounds than fat and urea would be produced; and, lastly, that the whole of the ready-formed fatty matter of the food has contributed to the fat stored up. It is obvious, however, that these assumptions are in part improbable and in part quite inadmissible, while the tendency of the error is, in each case, to show too large a proportion of the stored-up fat to have been possibly derived from the ready-formed fat and the nitrogenous constituents of the food.

It is obvious, therefore, that where the figures show an excess of carbon available from nitrogenous substance over that which would be required if the produced fat had been formed from it, the excess is overestimated, and, on the other hand, that where they show a deficiency of nitrogenous substance for such formation, the deficiency is underestimated; so that, in fact, the amount of fat required to be derived from other sources would be greater than the figures indicate. Indeed, according to the mode of calculation adopted, 100 of nitrogenous substance would yield 62 parts of fat, but it has been fully admitted in subsequent discussions that at most 51.4 parts of fat could possibly be derived from 100 parts of proteid substance, and more recently a much lower figure has been adopted.

After these general remarks we may now turn to the consideration of the results of the different experiments.

In experiment 1, two pigs of the same litter, of almost exactly equal weight, and, as far as could be judged, of similar character, were selected. One was killed at once, and the amount of total dry or solid matter of nitrogenous substance, of fat, and of mineral matter, determined in it. The other was then fed for a period of ten weeks on a mixture consisting of bean meal, lentil meal, and bran, each 1 part, and barley meal 3 parts, given ad libitum. It was then weighed, killed, and its composition determined as in the case of the other animal. In fact, the object of the experiment was to determine the composition of a "store" and of a "fat" pig, and to estimate the composition of its increase while fattening; and the data thus provided have formed the basis of the estimate of the fat in the increase, not only in the case of experiment 1, to which they directly apply, but in that of each of the other eight experiments, the results relating to which are recorded in the table. On this point it may be observed that, taking into consid-

eration the weight and condition of the animals at the commencement, the character of the foods, the length of the fattening period, the proportion of increase upon the original live weight, and the final condition of the animals, it may perhaps be concluded that the tendency of error in the calculations would be to give the proportion of fat in the increase somewhat too high in experiments 2 and 3, and somewhat too low in experiments 6, 7, 8, and 9. In experiments 4 and 5, however, the animals were the fattest in the series; and it will be seen further on that the high estimates of fat in the increase in their case are probably not too high—indeed, in experiment 5, even somewhat too low.

It might be supposed that—at any rate in the case of experiment 1—the results would be admirably adapted for our present purpose. But that experiment was made in 1850. That is nearly forty-five years ago, and before we had acquired sufficient evidence against the view then prevailing, namely, that the increase of the fattening animal was largely dependent on the richness of the food in nitrogenous constituents, and everybody having experience in the fattening of pigs will admit that in this case the food was much more highly nitrogenous than is recognized as most favorable for the fattening of the animal. In fact, it is seen that the proportion of the crude nonnitrogenous to 1 of crude nitrogenous substance in the food was only 3.6 instead of about 6 as in barley meal. There was, therefore, an excess of nitrogenous substance consumed.

Referring to the middle division of the table, the calculated results show that, for 100 increase in live weight 100 of nitrogenous substance was consumed in the food. Of this it is estimated that only 7.8 parts were stored up in the increase, leaving 92.2 parts available for the possible formation of fat.

It is next seen that the 100 of increase was estimated to contain 63.1 parts of fat, while the food supplied only 15.6 parts, leaving, therefore, at least 47.5 parts to be produced within the body. The figures show that this would require 36.6 parts of carbon, while 44 parts are estimated to have been available from the nitrogenous substance of the food; leaving, therefore, according to the mode of calculation adopted, 7.4 parts more carbon available than were required for the formation of the produced fat. Or, as shown in the bottom division of the table, for 100 carbon in the estimated newly-formed fat, 120.2 parts were available from the nitrogenous substance consumed in the food.

Here, then, the calculations afford no evidence that fat must have been produced from carbohydrates. But, as already explained, the mode of estimate adopted assumes the whole of the ready-formed fat in the food to have been stored up, and the whole of the carbon of the nitrogenous substance, beyond that in the animal increase and in the urea formed, to have been utilized for fat formation. Neither of these assumptions is, however, admissible; and it will be seen further on,

when due correction is made in regard to these points, that even in this experiment, with so abnormally high a proportion of nitrogenous substance in the food, it is pretty certain that some of the produced fat must have had its source in the carbohydrates.

In experiment 2 the food consisted of bean meal, lentil meal, bran, and maize meal, each given separately, and ad libitum; and in experiment 3, of an equal mixture of bean meal and lentil meal, also given ad libitum. It is seen that in both cases the proportion of crude non-nitrogenous to 1 of crude nitrogenous substance in the food was even lower than in experiment 1, being in experiment 2, 3.3, and in experiment 3 only 2, against 3.6 in experiment 1. Here again, as might be expected, with so high a proportion of nitrogenous substance in the food, the calculations show that there was more than sufficient carbon available from the nitrogenous substance of the food for the formation of all the fat that was estimated to be produced.

Experiments 4 and 5 show a very different result. In experiment 4 the food consisted of maize meal alone, and in experiment 5 of barley meal alone, in each case given ad libitum. In America, especially, maize meal is largely used for the fattening of pigs, almost, if not quite, alone, and in our own country barley meal is undoubtedly recognized as the most appropriate fattening food of the animal. It is seen that in experiment 4 with maize meal, the proportion of crude nonnitrogenous to 1 of nitrogenous substance in the food was 6.6, and in experiment 5 with barley meal, it was 6; or, in both cases very nearly that which is recognized as appropriate in the fattening food of the animal.

Accordingly, the calculations show much less nitrogenous substance consumed for the production of 100 increase in live weight, and much less left available for fat formation after deducting the amount estimated to be stored up in the increase. Then, as to the fat, the animals were undoubtedly much fatter than the analyzed "fat" pig. Deducting the amounts of fat supplied in the food from that in the increase, there remained in the one case 52.7 and in the other 58.8 parts formed within the body, requiring in the first case 40.6 and in the second 45.3 of carbon; while the amounts of carbon estimated to be available from the nitrogenous substance of the food were only 24.7 and 27.4 parts, leaving in the one case 15.9 and in the other 17.9 parts to be provided from other constituents of the food. Or, if the calculations are made for 100 carbon in the estimated newly-formed fat, the figures show that in one case 39.2 and in the other 39.5 per cent of the total carbon of the produced fat must have been derived from other constituents of the food.

In other words, even on this mode of calculation, nearly 40 per cent of the newly-formed fat must have had its source in the carbohydrates. We shall see further on that even a considerably larger proportion still must, in reality, have been so derived.

The peculiarity of the experiments 6, 7, 8, and 9 was that the food contained less ready-formed fat than in any of the other cases, and that a large proportion of the nonnitrogenous substance supplied was in the form either of pure starch, pure sugar, or both. In experiments 6, 7, and 8 a fixed quantity of lentil meal and bran, averaging 3 pounds 3 ounces of lentil meal and 9 ounces of bran, was given per head per day; and, in addition, in experiment 6, sugar ad libitum; in experiment 7, starch ad libitum, and in experiment 8, sugar and starch, each separately ad libitum. Lastly, in experiment 9, lentil meal, bran, sugar, and starch, were each given separately and ad libitum. It will be seen that the proportion of crude nonnitrogenous to 1 of crude nitrogenous substance was 4.1 in experiments 6 and 7, 4.7 in experiment 8, and only 3.9 in experiment 9; that is, the food contained a higher proportion of nonnitrogenous substance than in experiments 1, 2, and 3, but considerably lower than in experiments 4 and 5. Accordingly the final result of the calculations is intermediate between that for the other two series.

To go a little into detail, it is seen that, for 100 increase in live weight, the amount of nitrogenous substance estimated to be available for fat formation was, in this series, intermediate between that in the other two. With much less fatty matter supplied in the food, the amount of fat estimated to be newly formed was about the same as in the other cases. The amount of carbon estimated to be available for fat formation from the nitrogenous substance of the food was, in each case, notably less than the amount required for the production of the newly-formed fat. The indication is, therefore, that, in each case, a considerable proportion of the produced fat must have had its source in other than the nitrogenous constituents of the food.

The bottom division of the table shows that, reckoned for 100 carbon in the estimated newly-formed fat, in the first case 18.9, in the second 18.8, in the third 25.2, and in the fourth 14.1 per cent, or, on the average, about 20 per cent of the whole must have been derived from other sources—in fact, from the carbohydrates. Nor can there be any doubt that the figures underestimate the proportion of the produced fat which could not have had its source in the albuminoids of the food.

The general result of the whole series of experiments is, then, that when the food of the fattening animal contains an abnormally high amount and proportion of nitrogenous substance, enough of it will probably be available for the possible formation of all the fat produced in the body; but that when the amount and proportion of such substances in the food are only normal, or low, there will remain a large proportion of the produced fat which could not have had its source in the proteids, and must have been derived from the carbohydrates.

Referring to our results and conclusions as given above, Professor Voit, in a paper which he published in 1869,[1] admits that in the experi-

[1] Ztschr. Biol., 5 (1869).

ments in which there was only a medium albuminoid supply in the food, there was, as the figures stand, a considerable deficiency for the formation of the fat produced, and a still greater deficiency when the relation of the nitrogenous to the nonnitrogenous constituents was lower still, and hence it would appear that in these instances a considerable amount of fat had been derived from the carbohydrates. Still, he says he can not allow himself to consider that a transformation of carbohydrates into fat is proved thereby. He says he has not been able to get a clear view of the experiments from the figures recorded, and suggests several possible sources of error. He proposed that new experiments with geese and with pigs should be made, and in a subsequent conversation I had with him he expressed his willingness to undertake a conclusive experiment with pigs.

Weiske and Wildt[1] did undertake an investigation with pigs to determine the point. But one animal was fed on food so rich in nitrogen that it suffered in health, and the experiment had to be discontinued; and the other on food so poor that it fattened extremely slowly; and hence, at the conclusion, calculation showed that there was enough of the consumed nitrogenous matter available for fat formation to cover the whole of the fat which had been produced.

Prof. Emil von Wolff, in his work entitled "Die rationelle Fütterung der landwirthschaftlichen Nutzthiere, auf Grundlage der neueren Thierphysiologischen Forschungen," published in 1874, assumed that albumin was probably the exclusive source of the fat of the fattening Herbivora of the farm. But he made the reservation that the amounts of increase produced in relation to constituents consumed, which common observation showed may be obtained with pigs, and still more the results recorded of some direct experiments with those animals (presumably our own), are almost incomprehensible without assuming the direct concurrence of the carbohydrates in the formation of the fat. Nevertheless, he considered that such evidence was inconclusive, and that experiments with pigs should be made in a respiration apparatus to settle the question.

After the inconclusive results of Weiske and Wildt, and the publication of Professor Wolff's views, as above quoted, we carefully reviewed and recalculated many of the results of our feeding experiments, including some with oxen and with sheep, as well as those with pigs, in order to satisfy ourselves whether any doubt could be entertained of the views we had previously advocated.

The result of this examination, so far as the ruminants were concerned, was to show that, owing to the comparatively small amount of increase obtained with them from a given amount of constituents consumed, the quantity of nitrogenous substance passed through the system for the production of a given amount of increase was, in most cases, so large as to admit of the assumption that the whole of the fat formed

[1] Ztschr. Biol., 10 (1874).

might have had its source in transformed nitrogenous matter. As will be seen further on, however, some of the experiments with sheep showed that, at any rate, part of the fat stored up must have had some other source than the fatty matter and the proteids of the food.

The reconsideration of the results with pigs fully confirmed the view that, in many cases, much more fat had been produced than could possibly have been derived from transformed albumin of the food. We concluded, therefore, that we were not called upon to institute new experiments and decided, instead, again to direct attention to the results which had already been published.

Accordingly, I gave a paper on the subject, in the section for agriculture and agricultural chemistry, at the meeting of the Naturforscher Versammlung, held at Hamburg, in 1876, at which there were present a number of the chief agricultural chemists of Germany. I discussed the results given in Tables 69 and 70, and pointed out that, even according to the mode of calculation adopted, which supposes about 62 parts of fat to be producible from 100 parts of nitrogenous substance, the experiments 4 and 5, in which the proportion of the nonnitrogenous to the nitrogenous constituents in the food was the most appropriate for fattening, showed that about 40 per cent of the produced fat could not have had its source in the nitrogenous substance consumed; and that if, according to Henneberg and Voit, it were assumed that 100 parts of albumin can at most yield 51.4 of fat, the results would be much more striking still. They would, of course, be still more so if, as has more recently been estimated, only 42, instead of 51.4, parts of fat can be derived from 100 of albumin.

I next considered what amount of error in the estimates would have to be admitted to turn the scale, and to show that the whole of the produced fat might have been derived from the albuminoids of the food. After going into considerable detail on the point, it was concluded that any such range of error was simply impossible.

Further, it was maintained that, in the case of pigs fattening rapidly on their most appropriate fattening food, the amount of fat stored up in proportion to the amount of fat and nitrogenous substance consumed was so large that the question of whether or not the carbohydrates contribute to fat formation might be conclusively settled by a properly conducted feeding experiment with those animals, without any analysis of the feces or the urine, or any determination of the products of respiration. I stated that it was only necessary to select two animals of a breed of good fattening quality and as nearly alike as possible in character and in weight, a convenient size and weight being, say, about 90 pounds per head. Each should then be fed with ground barley of good quality, giving it by degrees, until both weighed about 100 pounds. Then slaughter one and determine its total amount of nitrogenous substance and of fat. Continue to feed the other with barley meal (and water) exclusively, as much as it will consume, until it

reaches a weight of about 200 pounds; then slaughter and analyze it as the first. The quantity and composition of the food must, of course, also be determined. Such an animal would probably consume about 500 pounds of barley and increase in live weight from 100 to 200 pounds in from eight to ten weeks, more or less, according to the quality of the animal, the quality of the food, and other conditions. It was desirable that the animals selected should have been feeding on fairly good food previously, so that the transition to full fattening food should not be too sudden. It was also, of course, desirable that the experiments should be made in duplicate if possible.

In the discussion which followed Professor Henneberg, who was, I believe, the first to have a Pettenkofer respiration apparatus constructed for experimenting with the larger animals of the farm, and had, perhaps, at that time conducted more experiments on feeding than any other agricultural chemist in Germany, said he did not doubt the formation of fat from carbohydrates in the case of pigs. He added that probably sooner or later the carbohydrates would be restored to their former position so far as fat formation in other animals was concerned, for already some experiments had shown that such formation was quite close upon the limits of the amount possibly derivable from the fat and albuminoid matters of the food. Prof. Emil von Wolff also spoke in the same sense, so far as pigs were concerned.

Since that time experiments have been made on the subject in Germany with various animals; but, even in those with pigs, the conditions above indicated as desirable, with a view to obtaining decisive results the most easily, were not followed.

Experiments were made with cows, by Voit at Munich,[1] by Wolff at Hohenheim,[2] and by G. Kühn at Möckern.[3] In those at Munich and at Hohenheim the amount of fat in the food and that possibly derivable from the albumin consumed very nearly corresponded with the amount of fat in the milk. In the experiment at Möckern, however, a small excess of milk fat was produced. None of those experiments, therefore, afforded evidence of the formation of fat from the carbohydrates.

In experiments made by Kern and Wattenberg, at Göttingen,[4] with sheep of various ages, in ten cases the fat stored up fell short by 24 to 64 per cent of that which could have been derived from the fatty matter and nitrogenous substance consumed. In one experiment, however, one animal was killed and the initial composition determined; and the other was fed for ten weeks, and the composition and digestibility of the food were determined. The results showed that 29.4 per cent of the fat stored up must have been derived from other sources

[1] Ztschr. Biol., 1869, p. 113.

[2] Die Versuchs-Stationen Hohenheim, Berlin, 1870, p. 50; also M. Fleischer in Virchow's Arch. Path. Anat., Band 51, 1870.

[3] Versuchs-Stationen, 1869, vol. 12, p. 451.

[4] Jour. Landw., Jahrg. 26, p. 549.

than the fat and the albumin of the food; and, even making all allowance for possible error, it was concluded that fat must have been derived from the carbohydrates consumed.

In other experiments at Göttingen, by T. Pfeiffer and Lehmann,[1] a similar result was obtained with a sheep fed with a considerable quantity of sugar.

In an experiment made by Wolff, at Hohenheim,[2] a young pig was fed for one hundred and eight days with barley and maize meal, with the addition of pure starch. The constituents digested were determined. Referring to the results Wolff says that, having regard simply to the amounts of constituents consumed, and of increase produced, it is scarcely possible to suppose that the quantity of fat which must have been stored up could have been formed without the cooperation of the carbohydrates. He points out that fat equal to only 29 per cent of the increase in live weight could have been produced from the fat and the albumin of the food; and in this calculation he takes the whole of the albumin as available, without reckoning any to have been stored up. He adds that, according to the percentage of fat in increase in the Rothamsted experiment No. 1, there must have been 60 per cent or more. According to our own calculation of Wolff's results it seems probable that about 60 per cent of the total fat in the increase must have been derived from carbohydrates. It is particularly to be observed that, in the case of this experiment, Wolff concluded that the formation of fat from the carbohydrates might be considered established, not only without any respiration apparatus, but even without any direct determination of fat in the animal.

Wolff quotes the results of experiments with pigs at Moscow, by Tschirwinsky, in 1880–81 and in 1881–82.[3] It was estimated that in the one case 61.6 per cent, and in the other 76.9 per cent, of the fat of the increase must have had its source in the carbohydrates of the food.

In an experiment made with a pig at Vienna by Meissl and Strohmer,[4] it was estimated that 82.2 per cent of the stored-up fat must have been derived from the carbohydrates consumed.

At Broskau, Weiske and B. Schulze,[5] made experiments with geese; and they concluded that in one case 13 per cent and in the other 17.6 per cent of the stored-up fat must have been derived from carbohydrates.

At Peterhof, near Riga, Chaniewski,[5] experimented with geese; and from the results concluded that in one case 71.1 per cent, in another 78.6 per cent, and in a third 86.7 per cent of the stored-up fat must have been derived from carbohydrates.

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[1] Jour. Landw., 1885, vol. 23, p. 337; also, 1886, vol. 34, p. 83.

[2] Die rationelle Fütterung der landwirtschaftlichen Nutztiere, 5te Aufl., 1888, p. 48.

[3] Versuchs-Stationen, 1883, Band 29, p. 317.

[4] Ber. Acad. Wissensch. Wien, 1883, Band 88, Part III.

[5] Die rationelle Fütterung der landwirtschaftlichen Nutztiere, 5te Aufl., 1888, p. 50.

Wolff also quoted recent experiments by A. von Planta and Erlenmeyer at Munich, with bees,[1] in which it was proved that wax had been formed from sugar.

Lastly, in 1880–81, Soxhlet made experiments with three pigs at the agricultural experiment station at Munich.[2] The animals were five to six months old; they were fed for a preliminary period of 321 days with equal but limited amounts of barley meal. No. 1 was then killed and analyzed; No. 2 was fed for 75 days, and No. 3 for 82 days, with 4.4 pounds steamed rice per head per day for most of the time, but only three-fourths as much afterwards. Meat extract was also given for 50 days. Finally Nos. 2 and 3 were killed and analyzed. Calculation showed that the increase of No. 2 contained 14.19 per cent of nitrogenous substance and 25.80 per cent of fat; and that of No. 3, 7.25 per cent of nitrogenous substance and 57.23 per cent of fat. That is, the increase of No. 3 contained only half as much nitrogenous substance, and more than twice as much fat, as that of No. 2; and even the higher proportion of fat (57.23) is low compared with that which would be obtained with animals of good breed and rapidly fattened on appropriate food given ad libitum; while the composition of the increase of No. 2, both as to nitrogenous substance and fat, can hardly be called that of fattening increase at all. Still, calculation showed that, of the total fat in the increase of No. 2, 79.38, and in that of No. 3, 81.84 per cent, must have been derived from the carbohydrates of the food.

Notwithstanding the extraordinary difference in the composition of the increase of Soxhlet's pigs, No. 2 and No. 3, after having been fed alike, he says that only our experiment No. 1 is admissible for calculation, because it is only in that case that the initial and final composition was determined in parallel animals. He, in fact, accepts our least conclusive result, obtained with food abnormally rich in nitrogenous substance, and repudiates our most conclusive experiments with appropriate fattening food. Accordingly, he maintains that we had only shown the probability of the formation of fat from the carbohydrates, and that his own results as above were the first to prove it.

I think the discussion of the results of the nine experiments recorded in Table 70 (p. 260) must have sufficed to show that in some of them a very large proportion of the fat of the increase must have been produced from the carbohydrates. The mode of calculation adopted showed, however, a maximum amount of the fat of the increase to have been possibly derivable from fatty matter in the food, a maximum amount of the nitrogenous substance of the food to be available for fat formation, and a maximum amount producible from a given amount of nitrogenous substance, and hence, a minimum amount necessarily derived from carbohydrates. But, as the results so calculated, and discussed with due reservation on these points, are those upon which we

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[1] Bienenzeitung, v. A. Schmidt, 1878, p. 181.

[2] Ztschr. landw. Ver. Bayern, 1881, pp. 423–436.

have for so many years maintained that the formation of fat from carbohydrates has been proved, and as it is those results, and the conclusions drawn from them, that have instigated so much subsequent investigation leading to the confirmation of our views, I have thought it desirable prominently to direct attention to the evidence as so brought out.

We have, however, as already said, long ago recalculated many of our feeding experiments, making allowance as far as practicable for the probable amount of indigestible and necessarily effete matters of the foods. We have also, as referred to at pages 252–255, arranged tables founded on our direct analytical results on the ten animals, showing the probable average percentage composition of the different descriptions of animal, each at eight gradationary points from the store to the very fat condition, and have applied the factors thus obtained, not only for the calculation of the composition of the increase in a number of cases of ordinary practice, and of direct experiment, but also for the recalculation of some of the results to which Table 70 relates. Accordingly, in the next table (71) are given the results obtained in experiment No. 1, which were inconclusive according to the original mode of calculation, and also those obtained in experiments 4 and 5, which, even as originally calculated, could leave no doubt of very considerable formation of fat from the carbohydrates.

All these recalculations are in the first place based on the assumption, since generally adopted by others, that 100 nitrogenous substance can at the most yield 51.4 of fat, instead of nearly 62, according to the original plan of calculation as adopted in the construction of Table 70. Then, each experiment is now calculated three ways: First, on the assumption that the whole of the fatty matter and nitrogenous substance of the food were digested; secondly, supposing that only 90 per cent, and thirdly, that only 80 per cent was digestible and available. Lastly, in the case of experiments 4 and 5, I have, after very carefully considering the weights and character of the animals and the duration of the fattening period, taken the initial and final composition, not as in Table 70 the same as in experiment 1, but the initial at a composition three-eighths in advance from the store to the fat condition, as in experiment 1, and the final composition at one-fourth in advance of fatness, compared with the fat pig of experiment 1. It is worthy of remark that this carefully reconsidered independent mode of estimate gives almost precisely the same percentage of nitrogenous substance, and precisely the same of fat, in the increase in experiment 4 as in the former estimate, namely, 5.4 instead of 5.3 per cent of nitrogenous substance, and in both cases 79 per cent of fat, the animals being all very fat. Again, the new mode of calculation gives for experiment 5, 6.4 per cent of nitrogenous substance, and 72.3 per cent of fat in the increase, instead of 6.5 and 71 per cent, as formerly adopted.

TABLE 71.—*Sources of the fat of the animal body. Abstract of results of experiments made at Rothamsted with pigs. (Results reckoning 100 nitrogenous substance in food may yield 51.4 fat.)*

	Experiment 1.—Bean meal, lentil meal, and bran, each 1 part; barley meal, 3 parts.			Experiment 4.—Maize meal ad libitum.			Experiment 5.—Barley meal ad libitum.		
Proportion of nitrogenous substance and fat digested	All.	90 p.ct.	80 p.ct.	All.	90 p.ct.	80 p.ct.	All.	90 p.ct.	80 p.ct.
Albuminoid ratio[1]	3.8	3.8	3.8	7.3	7.3	7.3	6.3	6.3	6.3
For 100 increase in live weight.									
Nitrogenous substance:									
In food	100	90	80	57	51.3	45.6	64	57.6	51.2
In increase	7.8	7.8	7.8	5.4	5.4	5.4	6.4	6.4	6.4
Available for fat formation	92.2	82.2	72.2	51.6	45.9	40.2	57.6	51.2	44.8
Fat:									
In increase	63.1	63.1	63.1	79	79	79	72.3	72.3	72.3
In food	15.6	14	12.5	26.3	23.7	21	12.4	11.2	9.9
Newly formed	47.5	49.1	50.6	52.7	55.3	58	59.9	61.1	62.4
Derivable from nitrogenous substance	47.4	42.3	37.1	26.5	23.6	20.7	29.6	26.3	23
From carbohydrates	.1	6.8	13.5	26.2	31.7	37.3	30.3	34.8	39.4
For 100 total fat in increase.									
Fat:									
From fat in food	24.7	22.2	19.8	33.3	30	26.6	17.2	15.5	13.7
Derivable from nitrogenous substance	75.1	67	58.8	33.5	29.9	26.2	40.9	36.4	31.8
Derivable from carbohydrates	.2	10.8	21.4	33.2	40.1	47.2	41.9	48.1	54.5
For 100 newly-formed fat.									
Fat:									
Derivable from nitrogenous substance	99.8	86.1	73.3	50.3	42.7	35.7	49.4	43	36.9
Derivable from carbohydrates	.2	13.9	26.7	49.7	57.3	64.3	50.6	57	63.1

[1] In the calculation of these ratios the nitrogen is, as in Table 70, multiplied by 6.3 to represent total nitrogenous substance; and for column 1 of each experiment no deduction is made. For all three columns of each experiment the crude fat is multiplied by 2.4 to bring it into its equivalent of starch. For column 1 the amount of nonnitrogenous substance, not fat, is taken without deduction; but for columns 2 and 3, as in the case of the nitrogenous substance and the fat, only 90 or 80 per cent respectively of the total is assumed to be digested.

Let us first just refer to the results of experiment 1, in which parallel animals were analyzed, but in which, as has been pointed out, the food was much more highly nitrogenous than is appropriate in the fattening food of the pig. Those given in column 1, in which it is assumed that the whole, both of the nitrogenous substance and of the fat of the food, was digestible and available, show that when we now reckon only 51.4 instead of about 62 parts of fat to be derivable from 100 nitrogenous substance, even this experiment indicates that the fat in the food and that derivable from the nitrogenous substance consumed, were scarcely sufficient to cover the whole of the fat of the increase. Obviously, too, if it be assumed, according to the more recent estimate, that only about 42 parts of fat can be derived from 100 of albuminoid sub-

stance, there would then, even in this experiment with such abnormally high nitrogenous food, be a considerable formation of fat from carbohydrates.

Turning to the results in the second column, which are calculated on the assumption that only 90 per cent of the nitrogenous substance and fatty matter of the food would be digested, it is seen that, for 100 increase in live weight, 6.8 parts, for 100 total fat in the increase 10.8 parts, or for 100 newly-formed fat 13.9 parts, must have been derived from carbohydrates.

Lastly, in regard to experiment 1, reckoning only 80 per cent of the nitrogenous substance and fat of the food to have been digested and available, the result would be that 13.5 out of 63.1 parts of fat in 100 of increase, must have had some other source than fat and nitrogenous substance of food; or reckoned for 100 total fat in the increase, 21.4 parts, or for 100 newly-formed fat, 26.7 parts, must have been derived from carbohydrates.

In regard to the alternative assumptions that only 90 or only 80 per cent of the nitrogenous and fatty matters of the food were digested, it may be stated that in Wolff's tables, published in Mentzel und v. Lengerke's landwirthschaftlicher Kalender for 1890, he reckons 88 per cent of the nitrogenous substance of beans, 89.9 per cent of that of lentils, 77.9 per cent of that of bran, 79.2 per cent of that of maize, and 77 per cent of that of barley, to be, on the average, digested; and of the fatty matter of these foods he reckons 87.5 per cent of that of beans, 84.6 per cent of that of lentils, 70.6 per cent of that of bran, 85.1 per cent of that of maize, but the whole, or 100 per cent of that of barley, to be digestible. So far, therefore, as experiment 1 is concerned, according to Wolff's factors, the truth would lie somewhere between the results supposing 90 and those supposing 80 per cent digested.

Even in this experiment then (No. 1), there is clear evidence of the formation of fat from the carbohydrates, when deduction is made for indigestible nitrogenous and fatty matters consumed, and when it is reckoned that only 51.4 parts of fat may be produced from 100 albuminoid substance. Obviously, if only 42 parts of fat, as assumed by some, can be formed from 100 albumin, the evidence is clearer still.

Turning now to experiment 4, in which the food was maize meal alone, given ad libitum, and the relation of nonnitrogenous to 1 of nitrogenous substance was much higher than in experiment 1, and much more appropriate for the rapid fattening of the pig, the results are much more decisive. They were, indeed, quite conclusive as originally calculated, without the emendations now adopted.

The results even as given in the first of the three columns, in the calculation of which it is assumed that the whole of the nitrogenous substance and fat of the food were digested and available, show that for 100 increase in live weight 26.2 parts of fat, for 100 total fat in increase

33.2, and for 100 newly-formed fat 49.7 parts must have been derived from carbohydrates.

Reckoning, as in the second column, that 90 per cent of the nitrogenous substance and fatty matter consumed were digestible and available, the calculations show that for 100 increase in live weight 31.7 parts of fat, of 100 total fat in increase 40.1 parts, and of 100 newly-formed fat 57.3 parts would be derived from carbohydrates. Or, reckoning as in the third column, that only 80 per cent of the nitrogenous substance and fat of the food were digested and available, the results show that for 100 increase in live weight 37.3 parts of fat, of 100 total fat in the increase 47.2 parts, and of 100 newly-formed fat 64.3 parts, or nearly two-thirds of the total produced fat, would have its source in the carbohydrates.

It may be observed that, in the case of this experiment with maize, the results given in the third column would very nearly accord with those which would be obtained if Wolff's average percentages of digestible constituents had been adopted.

Let us now refer to the results of experiment 5, in which the food was barley meal alone, given ad libitum, and the albuminoid ratio was nearly that recognized as most suitable for the rapid fattening of the pig.

The first of the three columns, calculated on the assumption that the whole of the nitrogenous substance and fat consumed were digested, shows that under such conditions there would be for 100 increase in live weight 30.3 parts of fat, for 100 total fat in increase 41.9 parts, and for 100 newly-formed fat 50.6 parts, or about half, must have been derived from other constituents than the fatty matter and nitrogenous substance of the food.

The results in the second column, calculated on the assumption that 90 per cent of the fatty matter and nitrogenous substance were digested, show that in 100 increase in live weight 34.8 parts of fat, in 100 of total fat in increase 48.1 parts, and of 100 newly-formed fat 57 parts must have been formed from carbohydrates.

Lastly, the results in the third column, reckoning only 80 per cent of the nitrogenous substance and fat to be digested, show that on this supposition of 100 increase in live weight 39.4 parts of fat, of 100 total fat in increase 54.5 parts, or of 100 newly-formed fat 63.1, or again nearly two-thirds, must have been derived from carbohydrates.

So much for the evidence of results relating to pigs in their bearing on the question of the sources of their fat, when fed on their appropriate fattening food. It is cumulative and decisive that at any rate a large proportion of the stored-up fat must have its source in other constituents than the fat and nitrogenous substance of the food; in other words, in the carbohydrates.

THE EXPERIMENTS AT ROTHAMSTED WITH SHEEP.

It has been pointed out that, compared with pigs, there is with ruminants a much smaller amount of increase obtained, in proportion both to their weight within a given time and to a given amount of food passed through the body, and that there is also a much larger amount of necessarily effete matter in their food; and that, therefore, the result of calculations of feeding experiments with them in regard to the question of the sources in the food of the fat stored up in the body are less conclusive. It will, nevertheless, be of interest to adduce some direct experimental evidence on the point.

Some time after the discussion at Hamburg, in 1876, two sets of experiments made at Rothamsted with sheep, in which the concentrated foods were barley or malt, and in which, therefore, the amount and proportion of nitrogenous substance consumed were low, were selected for calculation.

The first series comprised five pens with four or five sheep in each. The experiments had been made in the spring of 1849, and extended over a final fattening period of ten weeks. In each pen barley or malt was given in fixed quantity per head per day, and in each pen, also, mangels were given in addition ad libitum.

The second series also comprised five pens, but with twelve sheep in each. The experiments were made in the winter of 1863–64, and they extended over a final fattening period of twenty weeks. The animals were at an earlier stage of progress at the commencement, and not quite so mature at the conclusion, as those of the other series. In each pen barley or malt was given in fixed quantity per head, in each clover chaff also in fixed quantity, and in each roots were given ad libitum, Swedish turnips during the first sixteen weeks, and a mixture of one-fourth Swedes and three-fourths mangels during the last four weeks of the twenty.

The results of these two series of experiments with sheep, calculated to show their bearing on the question of the sources of the fat stored up by the animals, are given in Table 72:

TABLE 72.—*Sources of the fat of the animal body. Experiments at Rothamsted with sheep. (Assumed that 100 digestible nitrogenous substance in food may yield 51.4 fat.)*

	Fixed food: Barley or malt; mangels ad libitum.					Fixed food: Barley or malt, and clover chaff; roots (Swedes and mangels) ad libitum.				
	1.	2.	3.	4.	5.	1.	2.	3.	4.	5.
	Barley.	Malt and malt dust.	Barley, steeped.	Malt and malt dust, steeped.	Malt and malt dust, extra quantity.	Barley and clover chaff.	Malt and clover chaff.	Barley and clover chaff.	Malt and clover chaff.	Barley two-thirds, malt one-third, and clover chaff.
Per 100 increase in live weight.										
Nitrogenous substance:										
In fixed food (digestible)	25	23.3	19.9	25	27.9	52.4	51.1	55.8	55.9	58.6
In increase	6.5	6.5	6.5	6.5	6.5	7.5	7.5	7.5	7.5	7.5
Available for fat formation	18.5	16.8	13.4	18.5	21.4	44.9	43.6	48.3	48.4	51.1
Fat:										
In increase	74	74	74	74	74	69	69	69	69	69
In total food (digestible)	10.3	8.8	9.6	10.3	10.2	13.1	12.9	13	13.3	13.8
Newly formed	63.7	65.2	64.4	63.7	63.8	55.9	56.1	56	55.7	55.2
Derivable from nitrogenous substance	9.5	8.6	6.9	9.5	11	23.1	22.4	24.8	24.9	26.3
From other sources	54.2	56.6	57.5	54.2	52.8	32.8	33.7	31.2	30.8	28.9
Fat derivable from the nitrogenous substance of the roots, according to the percentage of it capable of fat formation.										
Fat from nitrogenous substance of roots:										
If 50 per cent capable of fat formation	22.2	20.8	24.4	26.6	23.3	14.1	14	14	14.2	14.8
If 60 per cent capable of fat formation	26.6	25	29.3	31.9	28	16.9	16.8	16.9	17	17.8
If 70 per cent capable of fat formation	31.1	29.1	34.2	37.2	32.6	19.7	19.6	19.7	19.9	20.7
If 80 per cent capable of fat formation	35.5	33.3	39	42.6	37.3	22.6	22.4	22.5	22.7	23.7
If 90 per cent capable of fat formation	40	37.4	43.9	47.9	41.9	25.4	25.2	25.3	25.6	26.6
If 100 per cent capable of fat formation	44.4	41.6	48.8	53.2	46.6	28.2	28	28.1	28.4	29.6

It will be seen that the form of the table is, so far as the facts will allow, the same as has been adopted in the case of the various experiments with pigs. A general description of the food of each series is given over the columns relating to the series, and at the head of each separate column is given a description of the limited food supplied to each pen.

The results are calculated for 100 increase in live weight. Referring to the upper division of the table, there are first shown the amounts of nitrogenous substance (digestible) in the fixed food, the amounts in the increase, and the difference = the amounts available for fat formation. Next are given the amounts of fat in the increase, in the total food

(digestible), and the difference = the newly-formed fat; the amounts derivable from the available nitrogenous substance in the fixed food and the difference = the amount required to be produced from other sources. Then, in the lower division of the table are given, for each pen, the amounts of fat derivable from the nitrogenous substance of the roots, on the alternative assumptions that 50, 60, 70, 80, 90 per cent, or the whole, of that which they contain will be digestible and available for fat formation.

It should be further explained that 80 per cent of the nitrogenous substance of barley or of malt is reckoned as digestible and available for the purposes of the system. Wolff's estimates were, in 1874, 80 per cent; in 1888, 77.3 per cent; and in 1890, 77 per cent. In malt dust 80 per cent is assumed to be digestible, against Wolff's estimate of 80 per cent in 1874 and 82 per cent in 1888 and 1890. In clover chaff two-thirds or 66.7 per cent of the nitrogenous substance is reckoned as digestible, against a range in Wolff's tables, according to quality, from 51.4 to 69.9 per cent. In the case of Swedish turnips and mangels Wolff assumes the whole of the nitrogenous substance to be digestible and available, drawing no distinction in this respect between the amounts existing as albuminoids, as amides or other nitrogenous compounds. To this point I shall have to refer in more detail presently.

Then, as to the fat of the foods: the percentage of it reckoned as digestible is that given in Wolff's tables of 1874. In the case of barley he then reckoned only 68 per cent of the total to be digestible, but more recently he has supposed the whole of it to be so. For clover chaff his figures are the same at all three periods, as they are also for mangels.

Let us now turn to the calculated results as given in the table, and first to those relating to the first series of five pens, in which the fixed food was either barley or malt, and the ad libitum food consisted of mangels only. As already said, the period of experiment comprised only the last ten weeks of fattening. Hence, it commenced at a somewhat advanced stage of progress, and the animals were, at the conclusion, probably fully as fat as, if not fatter than the sheep which had been analyzed as "fat." Taking into account the weight and condition of the animals at the beginning and at the end and the percentages of carcass and of inside fat in the live weight, it is calculated that the increase over this short finishing period, would contain 74 per cent of fat and only 6.5 per cent of nitrogenous substance.

On these assumptions the figures show that after deducting the estimated amount of nitrogenous substance in 100 of increase from the amount supplied in the fixed food, there remained in the different cases, 18.5, 16.8, 13.4, 18.5, and 21.4 parts of nitrogenous substance available from the fixed foods for the formation of fat.

Next as to the fat: deducting the amount of the digestible fat supplied in the total food from the fat in the increase, there remain in the respective cases 63.7, 65.2, 64.4, 63.7, and 63.8 parts, which must have

been newly formed. There is next shown the amount of this which may have been derived from the available nitrogenous substance of the fixed food; and it is seen that there remain 54.2, 56.6, 57.5, 54.2, and 52.8 parts out of the total of 74 in the 100 of increase, that must have been derived from other sources; in fact, either from the nitrogenous substance of the roots, or from the carbohydrates of the fixed food and the roots.

The next question is, whether the nitrogenous substance of the roots could have yielded the amounts of fat indicated to have been produced from other sources than the fat of the total food, and that derivable from the available nitrogenous substance of the fixed foods. Comparing the figures in the bottom line of the lower division of the table with those in the bottom line of the upper division it is seen that even on the impossible assumption that the whole of the nitrogen of the mangels existed in compounds of the same fat-forming value as the albuminoids, in neither of the five cases would the amount so available completely supply the amount required.

The amount of true albuminoid nitrogen varies very much in different descriptions of roots, and in the same description according to season, maturity, etc. Thus, at Rothamsted, we have found it in mangels as low as 20.5 per cent of the total nitrogen under unfavorable conditions of growth and ripening, and as high as 44.2 under favorable conditions. We generally assume in calculation that 40 per cent of the nitrogen of mangels will, on the average, exist as albuminoids, and Wolff's average figure, as given in 1888, is 36.1 per cent. The amount existing as amides will probably, in most cases, vary from 40 to 50 per cent or more, while there is frequently a considerable quantity as nitrates, the more the less ripe the roots, and we have sometimes found the amount to be more than 10 per cent of the total nitrogen of the roots.

It is clear, therefore, that even supposing as little as 50 per cent of the nitrogen of the roots to be available for, and capable of fat formation as assumed in the top line of the lower division of the table, that amount would generally include other than albuminoid compounds. Nevertheless, Wolff, in his table, assumes the whole of the nitrogen of roots to be digestible and available for the purposes of the system, since it has been shown that amides are transformed in the body and yield urea, leaving, therefore, by-products of transformation available for expenditure in respiration, and so protecting the true albuminoids or the carbohydrates.

There is, however, so far as I am aware, no direct experimental evidence yet at command indicating that the by-products of the transformation of amides may directly contribute to the formation of fat. Direct experiments have, however, shown that the heat of combustion of asparagin, for example, is less than half that of albumin, and, supposing that they do so contribute, it may safely be concluded that a given quantity of amide would yield less fat than an equal quantity of

albuminoid. As bearing upon this point it is to be borne in mind that, on the average, the amide bodies most frequently occurring in food stuffs have a higher percentage of nitrogen than the albuminoids. Wolff estimates that while the nitrogen of food should be multiplied by 6.25 to represent albuminoids, 5.5 would, on the average, be a more appropriate factor for calculating the amount of amide from that of the nitrogen. Further, he admits that so far as the nitrogen in potatoes, roots, and other food stuffs, exists as amides, the nutritive value of the food is reduced; nevertheless, as has been said in his tables, he assumes the whole of the nitrogenous substance of roots to be digestible and of equal value as such with the albuminoids.

Then, again, as generally more or less of the nitrogen in roots will exist as nitrates, it will so far not only have no food value, but it may be positively injurious. It may be added, that other things being equal, the higher the percentage of nitrogen in roots, the lower, as a rule, will be the proportion of it as albuminoids, and the higher that as amides, and as nitrates, etc. Further, in direct experiments at Rothamsted with sheep feeding on roots alone, it was found that while the animals even gained in weight on ripe roots, low in nitrogen, they actually lost on roots that were less ripe, high in nitrogen, and doubtless containing a larger proportion of their nitrogen as nonalbuminoid compounds.

From these various considerations it is obvious that by no means the whole of the nitrogen of the mangels can be estimated as having existed in compounds which could in their transformation yield the amount of fat possibly derivable from true albuminoids. However, with the great variation in the proportion of albuminoids and amides in roots, and the absence of exact knowledge as to the probable value, if any, direct or indirect, of amides for fat formation, it is impossible to form any certain estimate as to which of the percentages given alternatively in the lower division of the table most probably represents the amount of fat producible from the nitrogenous substance of the mangels given ad libitum in each of the 5 pens of the first series of experiments with sheep. It is, however, quite safe to conclude that very much less than the whole would be so available; and if we were to assume that of the nitrogenous constituents of the roots only the albuminoids would be available for fat formation, the figures given in the top line of the lower division of the table, according to which it is reckoned that only 50 per cent of the total nitrogenous compounds of the roots would be capable of fat formation, would in each case represent less than half the amount required.

It is quite clear that at any rate a large proportion of the fat of the increase estimated to be necessarily derived from other sources than the fat of the total food and the nitrogenous substance of the fixed food, must have been derived from other sources than the nitrogenous substance of the roots; in other words, it must have had its source in the carbohydrates of the fixed food or of the roots.

Let us now examine the evidence of the results of the second series of experiments on somewhat similar lines.

As in series 1, a fixed quantity of barley or malt was given in each pen, but now a fixed quantity of clover chaff also. This introduction of clover chaff into the fixed food brings us again face to face with the difficulty as to the estimation of the food value of the amides. As already said, the calculation of the amounts of the nitrogenous substance in the clover chaff which will be available, are made on the assumption that 66.7 per cent of the total nitrogen will be digestible, and so available; and this figure agrees fairly with Wolff's estimates. But this amount includes amides as well as albuminoids. In Wolff's most recent tables he estimates that the proportion of the nitrogen of clover hay existing in nonalbuminoid compounds may range from 13.9 to 29.9 per cent of the whole, and probably be on the average about 19 per cent. What proportion, however, of the two thirds of the total nitrogenous substance of clover hay, which is estimated to be digestible, will probably be nonalbuminoid, there is no evidence to show. In these circumstances I have, in the calculations, assumed the whole of the digestible nitrogenous substance of clover hay to have the food value of albuminoids. The figures will, therefore, doubtless overstate the amount of the nitrogenous substance consumed in the fixed foods, which is really available for nitrogenous increase and for fat formation.

Taking the figures as they stand, it is seen that, after deducting the amount of nitrogenous substance estimated to be stored up in 100 of increase from the amount supplied in the fixed food, there remain in the several experiments 44.9, 43.6, 48.3, 48.4, and 51.1 parts, possibly available for fat formation.

Then deducting the amount of digestible fat in the total food from the fat estimated to be stored up in the increase, there remain 55.9, 56.1, 56, 55.7, and 55.2 parts, which must have been newly formed. Deducting from these amounts, those producible from the available nitrogenous substance of the fixed foods, there remain 32.8, 33.7, 31.2, 30.8, and 28.9 parts, to be formed from other sources. Comparing with these amounts, those derivable from the nitrogenous substance of the roots, assuming, as shown in the bottom line of the table, that the whole of it would have the same value for fat formation as true albuminoids, it is seen that in four out of the five cases the fat so assumed to be formed would be less than that required.

In these experiments the roots consisted chiefly of Swedish turnips and in only small proportion of mangels. The evidence at command leads to the conclusion that in Swedish turnips a larger proportion of the total nitrogen exists as albuminoids and a less proportion as nitrates than in the more succulent mangels. We have found the proportion of the total nitrogen of Swedish turnips existing as albuminoids as low as 32.9 and as high as 55.8; and for the purposes of calculation we assume that, on the average, 45 per cent will be in that form. As large or a larger amount will, however, exist as amides than in mangels.

It is evident, therefore, that even if we assume 50 per cent of the total nitrogenous substance of the roots consumed in this second series of experiments to have been of value for fat formation, some amide will be included. But, even on the assumption that 50 per cent had the value of albuminoids for fat formation, less than half the amount of fat required would be derivable from the nitrogenous substance of the roots. Assuming, however, that the amides of the roots would, as such, have a certain, though not an equal, value with the albuminoids for fat formation; or that, as protectors of other constituents, they may contribute indirectly to such formation, there would still remain a considerable amount of the produced fat to be derived from other sources; that is, from carbohydrates.

Upon the whole, then, although the evidence of fat formation from the carbohydrates of the food is admittedly less direct in the case of sheep than in that of pigs, yet, when the foregoing results are carefully considered, with due regard to the facts which have been discussed, no doubt can be entertained that there was a considerable formation of fat from carbohydrates in both of the series of experiments with sheep. And when it is borne in mind that neither of these series of experiments was arranged for the purpose of elucidating this particular question, it must be admitted that the results are more definite and conclusive than might have been anticipated. Nor can there be any doubt that if experiments were made with oxen, under suitable conditions, they would yield equally conclusive evidence on the point. Indeed, as anticipated by Henneberg in the observations he made at Hamburg in 1876 we may consider that the carbohydrates are reinstated in their position in the formation of the fat of ruminants as well as in that of pigs.

SUMMARY ON THE SOURCES OF THE FAT OF THE ANIMALS OF THE FARM.

It was in 1865 (that is, nearly thirty years ago) that Voit first called in question the then very generally accepted opinions on the subject; and, as his evidence, derived from experiments with the omnivorous dog, accumulated, he more and more urged that his conclusions were equally applicable to Herbivora. His views on the point came to be very generally adopted by agricultural chemists in Germany, and, in 1874, Prof. Emil von Wolff adopted them, but with some reservation so far as pigs are concerned, in his text-book, entitled, "Die rationelle Fütterung der landwirthschaftlichen Nutzthiere, auf Grundlage der neueren thierphysiologischen Forschungen."

It has been already stated that in the discussion at Hamburg in 1876, Wolff more clearly admitted that pigs might behave exceptionally in the matter; whilst Henneberg assumed that ruminants also would prove to be exceptions to the application of Voit's views.

Since that date a number of experiments have been made in Germany and elsewhere, both with pigs and with ruminants, to elucidate

the point; and when the conditions of the experiments were suited to the object the results contributed to the reestablishment of the conclusion that the carbohydrates play a very direct and important part in the fat formation of the animals of the farm.

Further, in the edition of Wolff's work published in 1888, he almost unreservedly admits the rôle of the carbohydrates in the formation of at least a great part of the fat, not only of pigs, but of ruminants. Indeed, some years previously Voit himself had made substantial concessions on the point.

It happens, however, that about 1880 Dr. Armsby, now the director of the agricultural experiment station at the Pennsylvania State College, published a work entitled, "Manual of Cattle Feeding; a Treatise on the Laws of Animal Nutrition, and the Chemistry of Feeding Stuffs, in their Application to the Feeding of Farm Animals," which was a very good digest, chiefly of the work done in Germany, on the subject.

So far as the question of the sources of fat is concerned, it gives numerous tabular illustrations from Voit's work; and it follows almost exclusively the views of Voit and of Wolff at that time. He, however, quotes results obtained both with pigs and with other animals, which he admitted indicate, according to the figures, the formation of fat from the carbohydrates. But he considered that the data at command were not sufficient to solve the problem, and, with Wolff, assumed that the question could not be satisfactorily settled without experiments in a respiration apparatus. He also considered that estimates founded on the composition of the increase of fattening animals as determined at Rothamsted are uncertain. He nevertheless concluded that the carbohydrates may serve as a source of fat to swine, and under some circumstances to other animals also.

It happens that Dr. Armsby's book, founded to a great extent on Wolff's earlier editions, is the only work of the kind in the English language; and hence many of the rising generation of agricultural chemists, both in this country and in America, have adopted the view that the albuminoids are the main, if not the exclusive, source of the fat of our farm stock and of the butter of cows' milk.

Under these circumstances it seemed desirable to consider in some detail both the experimental evidence bearing upon the question and the discussions which have taken place in regard to it during the last quarter of a century or more. It must be admitted that the importance of the carbohydrates as a direct source of much, if not of the whole, of the fat stored up in the animals which the farmer feeds has been clearly reestablished. I have reason to believe that Dr. Armsby himself adopts the change of view, though it will probably be some time before the truth is thoroughly recognized by the younger agricultural chemists.

It was maintained by Voit and others that to establish the formation of fat from the carbohydrates, it must be experimentally shown that

the fat deposited was in excess of that supplied by the food, plus that which could be derived from transformed albumin. But it is obvious that the mere fact that the food contained enough nitrogenous substance for the formation of all the fat that had been produced, would of itself be no proof that that substance had been its source. It has been seen, however, that Voit's requirement was amply fulfilled in the Rothamsted experiments, both with pigs and with sheep; and hence it must be admitted to be proved that at any rate some of the stored-up fat must have had another source, which could only be the carbohydrates.

In winding up the discussion I perhaps can not do better than reiterate the conclusions given in our paper on the subject in 1866, namely:

(1) That certainly a large proportion of the fat of the Herbivora fattened for human food must be derived from other substances than fatty matter in the food.

(2) That when fattening animals are fed upon their most appropriate food, much of their stored-up fat must be produced from the carbohydrates it supplies.

(3) That nitrogenous substance may also serve as a source of fat, more especially when it is in excess, and the supply of available nonnitrogenous constituents is relatively defective.

FOOD AND MILK PRODUCTION.

Milk production and the dairy industry are of such great and growing importance, and their various branches involve so many points of interest, that much time and space would be required to adequately discuss them. But when considering what are the animal products of value derived from the consumption of food on the farm, it would obviously be inappropriate not to refer, however briefly, to the question of milk production in some of its aspects.

Attention must, however, be confined almost exclusively to the great difference in the demands made on the food—on the one hand for the production of meat, that is of animal increase, and on the other for the production of milk. Not only do cows of different breeds yield different quantities of milk, and milk of characteristically different composition, but individual animals of the same breed have very different milk-yielding capacity; and whatever the capacity of a cow may be, she has a maximum yield at one period of her lactation which is followed by a gradual decline. Hence, in comparing the amount of constituents stored up in the fattening increase of an ox with the amounts of the same constituents removed in the milk of a cow, we must assume a wide range of difference in the yield of milk.

Accordingly Table 73 shows the amounts of nitrogenous substance, of fat, of nonnitrogenous substance not fat, of mineral matter, and of total solid matter carried off in the weekly yield of milk of a cow on the alternative assumptions of a produce of 4, 6, 8, 10, 12, 14, 16, 18, or 20 quarts per head per day; and, for comparison, there is given at the

bottom of the table the amounts of nitrogenous substance, of fat, of mineral matter, and of total solid matter in the weekly increase in live weight of a fattening ox of an average weight of 1,000 pounds; first on the assumption of a weekly increase of 10 pounds, and secondly of 15 pounds.

The estimates of the amounts of constituents in the milk are based on the assumption that it will contain 12.5 per cent of total solids, consisting of 3.65 albuminoids, 3.50 butter fat, 4.60 sugar, and 0.75 of mineral matter. The estimates of the constituents in the fattening increase of oxen are founded on the determinations at Rothamsted of such increase as already described.

TABLE 73.—*Comparison of the constituents of food carried off in milk and in the fattening increase of oxen.*

[1 gallon = 10.33 pounds.]

	Nitrogenous substance.	Fat.	Non-nitrogenous substance not fat (sugar).	Mineral matter.	Total solid matter.
In milk per week.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
If 4 quarts per head per day	2.64	2.53	3.33	0.54	9.04
If 6 quarts per head per day	3.96	3.80	4.99	.81	13.56
If 8 quarts per head per day	5.28	5.06	6.66	1.08	18.08
If 10 quarts per head per day	6.60	6.33	8.32	1.35	22.60
If 12 quarts per head per day	7.92	7.59	9.99	1.62	27.12
If 14 quarts per head per day	9.24	8.86	11.65	1.89	31.64
If 16 quarts per head per day	10.56	10.12	13.32	2.16	36.16
If 18 quarts per head per day	11.88	11.39	14.98	2.43	40.68
If 20 quarts per head per day	13.20	12.65	16.65	2.70	45.20
In increase in live weight, per week, oxen.					
If 10 pounds increase	.75	6.35	....	.15	7.25
If 15 pounds increase	1.13	9.53	....	.22	10.88

Referring to the very wide range of yield of milk per head per day which the figures in the table assume, it may be remarked that it is by no means impossible that the same animal might yield the largest amount, namely, 20 quarts, or 5 gallons per day near the beginning and only 4 quarts or 1 gallon, or even less, toward the end of her period of lactation. At the same time an entire herd of, say, Shorthorns or Ayrshires, of fairly average quality, well fed, and including animals at various periods of lactation, should not yield an average of less than 8 quarts, or 2 gallons, and would seldom exceed 10 quarts, or 2½ gallons, per head per day the year round.

For the sake of illustration then, let us assume an average yield of milk of 10 quarts, equal to 2½ gallons, or between 25 and 26 pounds per head per day; and let us compare the amount of constituents in the weekly yield at this rate with that in the weekly increase of the fattening ox at the higher rate assumed in the table, namely, 15 pounds per 1,000 live weight, or 1.5 per cent per week.

Thus, while of the nitrogeneous substance of the food the amount stored up in the fattening increase of an ox will be only 1.13 pounds,

the amount carried off as such in the milk would be 6.6 pounds, or nearly six times as much. Of mineral matter, again, while the fattening increase would only require about 0.22 pound, the milk would carry off 1.35 pounds, or again about six times as much. Of fat, however, while the fattening increase would contain 9.53 pounds, the milk would contain only 6.33 pounds, or only about two-thirds as much. On the other hand, while the fattening increase contains no other nonnitrogenous substance than fat, the milk would carry off 8.32 pounds in the form of milk sugar. It may be observed that this amount of milk sugar, reckoned as fat, would correspond approximately to the difference between the fat in the milk and that in the fattening increase.

From the foregoing comparison it is evident that the drain upon the food is very much greater for the production of milk than for that of meat. This is especially the case in the important item of nitrogenous substance, and if, as is frequently assumed, the butter fat of the milk is, at any rate largely, derived from the nitrogenous substance of the food, so far as it is so, at least about two parts of such substance would be required to produce one of fat. On such an assumption, therefore, the drain upon the nitrogenous substance of the food would be very much greater than that indicated in the table as existing as nitrogenous substance in the milk. To this point I shall refer again presently.

I will next call attention to the amounts of food and of certain of its constituents consumed for the production of a given amount of milk. This point is illustrated in Table 74, which shows the constituents consumed per 1,000 pounds live weight per day, in the case of the Rothamsted herd, then of 30 cows, in the spring of 1884.

TABLE 74.—*Constituents consumed per 1,000 pounds live weight per day for sustenance and for milk production, the Rothamsted herd of thirty cows, spring, 1884.*

	Total dry substance.	Digestible.		
		Nitrogenous substance.	Nonnitrogenous substance (as starch).	Total nitrogenous and nonnitrogenous substance.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
3.1 pounds cotton cake	2.76	1.07	1.50	2.57
2.7 pounds bran	2.33	.33	1.09	1.42
2.8 pounds hay-chaff	2.34	.15	1.18	1.33
5.6 pounds oat-straw-chaff	4.64	.08	2.21	2.29
62.8 pounds mangels	7.85	1.01	5.73	6.74
Total	19.92	[1]2.64	[1]11.71	14.35
Required for sustenance		.57	7.40	7.97
Available for milk		2.07	4.31	6.38
In 23.3 pounds milk		.85	3.02	3.87
Excess in food		1.22	1.29	2.51
Per 1,000 pounds live weight: Wolff	24	2.5	[2]12.5	15.4

[1] Albuminoid ratio, 1–4.4.

[2] Exclusive of 0.4 fat; albuminoid ratio, 1–5.4.

On the left hand are shown the actual amounts of the different foods consumed per 1,000 pounds live weight per day; and in the respective columns are recorded—first the amounts of total dry substance which the foods contained and then the amounts of digestible nitrogenous, digestible nonnitrogenous (reckoned as starch), and digestible total organic substance, which the different foods would supply; these being calculated according to our own estimates of the percentage composition of the foods, and to Wolff's estimates of the proportion of the several constituents which would be digestible.

The first column shows that the amount of total dry substance of food actually consumed by the herd, per 1,000 pounds live weight per day, was scarcely 20 pounds, while Wolff's[1] estimated requirement, as stated at the foot of the table, is 24 pounds. But his ration would doubtless consist in larger proportion of hay and straw-chaff, containing a larger proportion of indigestible and effete woody fiber. The figures show, indeed, that the Rothamsted ration supplied, though nearly the same, even a somewhat less amount of total digestible constituents than Wolff's.

Of digestible nitrogenous substance, the food supplied 2.64 pounds per day, while the amount estimated to be required for sustenance merely is 0.57 pound, leaving, therefore, 2.07 pounds available for milk production. The 23.3 pounds of milk yielded per 1,000 pounds live weight per day would, however, contain only 0.85 pound, and there would thus remain an apparent excess of 1.22 pounds of digestible nitrogenous substance in the food supplied. But against the amount of 2.64 pounds actually consumed, Wolff's estimate of the amount required for sustenance and for milk production is 2.5 pounds, or but little less than the amount actually consumed at Rothamsted. On the assumption that the expenditure of nitrogenous substance in the production of milk is only in the formation of the nitrogenous substances of the milk, there would appear to have been a considerable excess given in the food. But Wolff's estimate assumes no excess of supply, and that the whole is utilized; the fact being that he supposes the butter fat of the milk to have been derived largely, if not wholly, from the albuminoids of the food.

It has been shown that although it is possible that some of the fat of a fattening animal may be produced from the albuminoids of the food, certainly the greater part of it, if not the whole, is derived from the carbohydrates. But the physiological conditions of the production of milk are so different from those for the production of fattening increase that it is not admissible to judge of the sources of the fat of the one from what may be established in regard to the other. It has been assumed, however, by those who maintain that the fat of the fattening animal is formed from albuminoids, that the fat of milk must be formed in the same way. Disallowing the legitimacy of such a

[1] Landw. Fütterungslehre, 5te Aufl., 1888, p. 249.

deduction, there do, nevertheless, seem to be reasons for supposing that the fat of milk may at any rate in larger proportion than that of fattening increase, be derived from albuminoids.

Thus, as compared with fattening increase, which may in a sense be said to be little more than an accumulation of reserve material from excess of food, milk is a special product of a special gland for a special normal exigency of the animal. Further, while common experience shows that the herbivorous animal becomes the more fat the more, within certain limits, its food is rich in carbohydrates, it points to the conclusion that both the yield of milk and its richness in butter are more connected with a liberal supply of the nitrogenous constituents in the food. Obviously, so far as this is the case, it may be only that thereby more active change in the system, and therefore greater activity of the special function, is maintained. The evidence at command is, at any rate not inconsistent with the supposition that a good deal of the fat of milk may have its source in the breaking up of albuminoids; but direct evidence on the point is still wanting, and supposing such breaking up to take place in the gland the question arises, What becomes of the by-products? Assuming, however, that such change does take place, the amount of nitrogenous substance supplied to the Rothamsted cows would be less in excess of the direct requirement for milk production than the figures in the table would indicate—if, indeed, in excess at all.

The figures in the column relating to the estimated amount of digestible nonnitrogenous substance reckoned as starch, show that the quantity actually consumed was 11.71 pounds, while the amount estimated by Wolff to be required was 12.5 pounds besides 0.4 pound of fat. The figures further show that deducting 7.4 pounds for sustenance from the quantity actually consumed, there would remain 4.31 pounds available for milk production while only about 3.02 would be required, supposing that both the fat of the milk and the sugar had been derived from the carbohydrates of the food, and according to this calculation there would still be an excess in the daily food of 1.29 pounds.

It is to be borne in mind, however, that estimates of the requirement for mere sustenance are mainly founded on the results of experiments in which the animals are allowed only such a limited amount of food as will maintain them without either loss or gain when at rest. But physiological considerations point to the conclusion that the expenditure, independently of loss or gain, will be the greater the more liberal the ration; and hence it is probable that the real excess, if any, over that required for sustenance and milk production, would be less than that indicated in the table, which is calculated on the assumption of a fixed requirement for sustenance for a given live weight of the animal.

Supposing that there really was any material excess of either the nitrogenous or the nonnitrogenous constituents supplied over the requirement for sustenance and milk production, the question arises whether or to what extent it conduced to increase in live weight of the animals, or whether it was in part or wholly voided and so wasted?

It would obviously be of interest to trace the connections between variation in the quantity and composition of the food, and the quantity and composition of the milk yielded. But when the influence on the result of breed, of varying character of individual animals, of period of lactation, and of other circumstances, are borne in mind it will be seen that to treat the subject at all adequately would involve a great deal of detailed illustration and consideration, and occupy very much more space than could appropriately be devoted to it in this place. I must, indeed, limit further reference to the subject of milk production to one more illustration, showing the influence of period of the year, with its characteristic changes of food, on the quantity and composition of the milk.

The first column of the second division of Table 75 shows the average yield of milk per head per day of the Rothamsted herd, averaging about 42 cows, almost exclusively Shorthorns, in each month of the year, over six years, 1884–1889 inclusive, and the succeeding columns show the amounts of butter fat, of solids-not-fat, and of total solids in the average yield per head per day in each month of the year, calculated, not according to direct analytical determinations made at Rothamsted, but according to the results of more than 14,000 analyses made under the superintendence of Dr. Vieth in the laboratory of the Aylesbury Dairy Company, in 1884;[1] the samples analyzed representing the milk from a great many different farms in each month.

TABLE 75.—*Percentage composition of milk each month of the year, also average yield of milk, and of constituents, per head per day each month, calculated according to Rothamsted dairy records.*

Month.	Average composition of milk each month, 1884 (Dr. Vieth, 14,235 analyses).				Rothamsted dairy.			
					Average yield of milk per head per day, 6 years.	Estimated quantity of constituents in milk per head per day each month.		
	Specific gravity.	Butter fat.	Solids-not-fat.	Total solids.		Butter fat.	Solids-not-fat.	Total solids.
		Per ct.	*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
January	1.0325	3.55	9.34	12.89	*a*20.31	0.72	1.90	2.62
February	1.0325	3.53	9.24	12.77	22.81	.80	2.11	2.91
March	1.0323	3.50	9.22	12.72	24.19	.85	2.23	3.08
April	1.0323	3.43	9.22	12.65	26.50	.91	2.44	3.35
May	1.0324	3.34	9.30	12.64	31.31	1.05	2.91	3.96
June	1.0323	3.31	9.19	12.50	30.81	1.02	2.83	3.85
July	1.0319	3.47	9.13	12.60	28.00	.97	2.56	3.53
August	1.0318	3.87	9.08	12.95	25.00	.97	2.27	3.24
September	1.0321	4.11	9.17	13.28	22.94	.94	2.11	3.05
October	1.0324	4.26	9.27	13.53	21.00	.89	1.95	2.84
November	1.0324	4.36	9.29	13.65	19.19	.84	1.78	2.62
December	1.0326	4.10	9.29	13.39	19.31	.79	1.79	2.58
Mean	1.0323	3.74	9.22	12.96	24.28	.90	2.24	3.14

a Average over 5 years only, as the records did not commence until February, 1884.

It should be stated that the Rothamsted cows had cake throughout the year, at first 4 pounds per head per day, but afterwards graduated

[1] The Analyst, April, 1885, Vol. X, p. 67.

according to the yield of milk, on the basis of 4 pounds for a yield of 28 pounds of milk, the result being that then the amount given averaged more per head per day during the grazing period, but less earlier and later in the year. Bran, hay and straw chaff, and roots (generally mangels), were also given when the animals were not turned out to grass. The general plan was, therefore, to give cake alone in addition, when the cows were turned out to grass, but some other dry food, and roots, when entirely in the shed during the winter and early spring months.

Referring to the column showing the average yield of milk per head per day each month, over the six years, it will be seen that during the six months, January, February, September, October, November, and December, the average yield was sometimes below 20 pounds, and on the average only about 21 pounds of milk per head per day, while over the other six months it averaged 27.63 pounds, and over May and June more than 31 pounds per head per day. That is to say, the quantity of milk yielded was considerably greater during the grazing period than when the animals had more dry food and roots, instead of grass.

Next referring to the particulars of composition, according to Dr. Vieth's results, which may well be considered as typical for the different periods of the year, it is seen that the specific gravity of the milk was only average, or lower than average, during the grazing period, but rather higher in the earlier and later months of the year. The percentage of total solids was rather lower than the average at the beginning of the year, lowest during the chief grazing months, but considerably higher in the later months of the year, when the animals are kept in the shed and receive more dry food. The percentage of butter fat follows very closely that of the total solids, being the lowest during the best grazing months, but considerably higher than the average during the last four or five months of the year, when more dry food is given. The percentage of solids-not-fat is considerably the lowest during the later months of the grazing period, but average or higher than average during the earlier and later months of the year.

It may be observed that according to the average percentages given in the table a gallon of milk will contain more of both total solids and of butter fat in the later months of the year; that is, when there is less grass and more dry food given.

Turning now to the last three columns of the table, it is seen that although, as has been shown, the percentage of the several constituents in the milk is lower during the grazing months, the actual amounts contained in the quantity of milk yielded per head are distinctly greater during those months. Thus, the amount of butter fat yielded per head per day is above the average of the year, from April to September, inclusive; the amounts of solids-not-fat are over average from April to

August, inclusive; and the amounts of total solids yielded are average or over average from April to August, inclusive.

From the foregoing results it can not be doubted that the quantity of milk yielded per head is very much the greater during the grazing months of the year, but that the percentage composition of the milk is lower during that period of higher yield, and considerably higher during the months of more exclusively dry-food feeding. Nevertheless, owing to the much greater quantity of milk yielded during the grazing months, the actual quantity of constituents yielded per cow is greater during those months than during the months of higher percentage composition, but lower yield of milk per head. It may be added that a careful consideration of the number of newly-calved cows brought into the herd each month shows that the results as above stated were perfectly distinct, independently of any influence of the period of lactation of the different individuals of the herd.

The few results which have been brought forward in relation to milk production are admittedly quite insufficient adequately to illustrate the influence of variation in the quantity and composition of the food on the quantity and composition of the milk yielded. Indeed, owing to the intrinsic difficulties of experimenting on such a subject, involving, as has been pointed out, so many elements of variation besides those which it is sought to investigate, any results obtained have to be interpreted with much care and reservation. Nevertheless, exercising such care and reservation in regard to the numerous results of ourselves and others which are at command, it may be taken as clearly indicated that within certain limits high feeding, and especially high nitrogenous feeding, does increase both the yield and the richness of the milk. But it is evident that when high feeding is pushed beyond a comparatively limited range the tendency is to increase the weight of the animal; that is, to favor the development of the individual, rather than to enhance the activity of the functions connected with the reproductive system. This is, of course, a disadvantage when the object is to maintain the milk-yielding condition of the animal, but when a cow is to be fattened off it will be otherwise.

It has been stated that early in the period of six years in which the Rothamsted results that have been quoted were obtained the amount of oil cake given was graduated according to the yield of milk of each individual cow, as it seemed unreasonable that an animal yielding, say, only 4 quarts per head per day should receive, besides the home foods, as much cake as one yielding several times as much. The obvious supposition is that any excess of food beyond that required for sustenance and milk production would tend to increase the weight of the animal, which, according to the circumstances, may or may not be desirable. But there remains the important question whether the period of lactation is lengthened, or the yield of the higher yielding cows is maintained the longer, by an increased amount of food; or whether, on the other

hand, the period of lactation or the yield of milk is reduced by the limitation of the supply of food? The point is, at any rate, deserving of careful experiment and observation.

It may be observed that direct experiments at Rothamsted confirm the view arrived at by common experience, that roots, and especially mangels, have a favorable effect on the flow of milk. Further, the Rothamsted experiments have shown that a higher percentage of butter fat, of other solids, and of total solids was obtained with mangels than with silage as the succulent food. The yield of milk was, however, in a much greater degree increased by grazing than by any other change in the food, and with us, at any rate, the influence of roots comes next in order to that of grass, though far behind it in this respect. But with grazing, as has been shown, the percentage composition of the milk is considerably reduced, though owing to the greatly increased quantity yielded the amount of constituents removed in the milk while grazing may nevertheless be greater per head per day than under any other conditions.

Lastly, it has been clearly illustrated how very much greater is the demand upon the food, especially for nitrogenous and for mineral constituents in the production of milk, than in that of fattening increase.

FOOD AND MANURE.

At the commencement of this section on the feeding of animals it was shown by reference to a special example how large was the proportion of the constituents of the crops grown in a rotation which was retained on the farm for further use; in fact, for consumption by animals or for litter. It was shown that in the case selected for illustration there would be so retained on the farm for such further use more than two-thirds of the total vegetable substance grown, more than half of the nitrogen of the crops, and about six-sevenths of the total mineral matter, while of the individual mineral constituents of the crops, less than half of the phosphoric acid, but about four-fifths of the potash would be retained.

Of course, in the very varied practice of agriculture at the present day, there will sometimes be larger and sometimes smaller proportions of the various constituents of the crops at once sold off or retained on the farm, but the example given may be taken as essentially typical, and as so far conveying a very useful impression on the subject. But besides the constituents of the home-grown rotation crops retained upon the farm for food and litter there will be more or less produce from grass land, while modern practices frequently involve the purchase of a considerable quantity of imported food stuffs.

Results relating to the feeding of animals for the production of meat and of milk have been considered, and I have now to discuss the subject of feeding as a source of manure. Numerous Rothamsted experiments have shown how small is the proportion of the various con-

stituents consumed in food by fattening or even by growing animals which is stored up in their increase, and which will, therefore, be lost to the manure. In the production of milk, however, it has been shown that the loss to the manure is very much greater.

Of the mineral matters of the food, we know that there need be no loss to the manure beyond that carried off in the animal increase or in milk. Of the nonnitrogenous organic substance of the food, a very large proportion is lost by the respiration of the animals, and a not inconsiderable quantity contributes to the animal increase or milk, and what remains for manure is of no material value as a direct supply of constituents, and of comparatively little by the action of its products of decomposition within the soil. Indeed, the most important point to consider is, What proportion of the nitrogen of the food remains for manure? As has been shown, and as will be further illustrated presently, only a comparatively small proportion is carried off in animal increase, but a much larger amount is lost to the manure in the production of milk. But the further questions arise, Is there any, so to speak, vital exhalation of nitrogen, or of any compounds of it, by the animal? Or may we estimate that the whole of that consumed which is not carried off in the animal increase or in milk will be found in the solid and liquid dejections, and so remain for manure? Or, on the other hand, Is there any assimilation by the animal of the free nitrogen of the atmosphere? The further practical question still remains, Is there any material loss of nitrogen after the solid and liquid excretions leave the body and before their utilization within the soil for the production of future crops?

First, then, is there any vital exhalation by the animal of nitrogen or of any of its compounds?

Obviously this is a question which could not be experimentally investigated before definite knowledge was attained in regard to the composition of the atmosphere. But after such knowledge had been acquired, rather more than a century ago, the subject of the mutual relations of the atmosphere and of vegetable and animal growth came to be studied, and, among other points, it was sought to be determined whether, on the one hand, the free nitrogen was assimilated by animals; or, on the other, whether it was exhaled at the expense of the nitrogenous substance of the food, of the blood, or of the more fixed substance of the body.

Commencing toward the end of the last century numerous investigations have been undertaken from various points of view bearing upon the subject; and among the investigators or writers may be named Lavoisier, Laplace, Séguin, Dalton, Sir H. Davy, Pfaff, Provençal and Humboldt, Allen and Pepys, Despretz and Dulong, Brunner and Valentin, Marchand, von Erlach, Baumert, Regnault and Reiset, Berthollet, Milne-Edwards, and C. G. Lehmann, besides others more recently.

It is impossible shortly, and at the same time adequately, either to describe or to criticise the numerous and upon the whole discordant results that have been obtained in regard to the question of the assimilation or exhalation of free nitrogen by animals. It is noticeable that the earlier investigators, Lavoisier, Laplace, and Séguin, concluded that the amount of nitrogen expired was neither more nor less than that inspired, and in this view they are in the main supported by the conclusions, though not entirely by the results, of Allen and Pepys, of Brunner and Valentin, and von Erlach. In favor of the view that free nitrogen is absorbed and assimilated may be cited the opinions of Sir Humphrey Davy and of Pfaff, so far as certain warm-blooded animals are concerned, and of Provençal and Humboldt and of Baumert in regard to fish. On the other hand, that there is evolution of free nitrogen has been concluded by Sir H. Davy, Berthollet, Dulong, and Despretz, Magnus, Marchand, Grassi, Regnault and Reiset, and C. G. Lehmann.

In regard to evolution, the most extensive and elaborate experiments are those of Regnault and Reiset. But the amounts which their results indicated would imply the loss in that way of an incredibly large proportion of the total nitrogen consumed in the food, while Liebig estimated that the evolution which Dulong assumed was so great that in the case of one of the experimental animals, the whole of the nitrogen of the body would be lost in 7 days; and that at the rate assumed by Despretz the nitrogen of one pound of flesh would go off in thirty-one hours.

Then the results indicating absorption are the most pronounced in the experiments with fish. The question arises, therefore, whether in their case the result may not be explained by supposing that oxygen has been absorbed from the air within the body, especially in the swimming bladder, and nitrogen stored up in its place, under the conditions of limited supply of oxygen from external sources, to which the animals have generally been subjected during experiment?

Upon the whole it must be concluded that from a variety of causes, connected, sometimes with the conditions under which the animals were placed under experiment, sometimes with the circumstances under which the samples assumed to represent the inspired and expired air, respectively, were taken for analysis, and sometimes with the methods of analysis themselves, the results of the experiments on respiration which have been referred to have not been sufficiently free from doubt to be accepted as establishing so important a conclusion as either the assimilation of free nitrogen by animals or the evolution of it from its compounds within the body.

The next point to consider is, whether there is any loss of ammonia or of other compounds of nitrogen in the breath or by the skin.

Louis Thompson, Thiry, Grouven, and others have found some emanation of ammonia, but Lossen and others consider it doubtful whether the ammonia in the air itself might not account for the results.

Various experiments have been made to determine the loss of nitrogen in sweat. In the sweat of man, ammonia and urea have been found. In the sweat of a horse, Grandeau and Leclerc[1] found ammonia, urea, and albumin. Prof. F. Smith, of Aldershot,[2] has also examined the sweat of horses. Besides various inorganic salts, he found ammonia and 3.381 per cent of albumin. He reckons that a pint of sweat will thus contain 0.676 ounce of albumin, and that this amount would be equivalent to the nitrogen in 5¾ ounces of oats. He further thinks it probable that the reduction of sweating by clipping would, with hard work, be equivalent to 1 pound of corn per day.

It seems safe to conclude, that the loss of combined nitrogen by gaseous emanations from the lungs and skin is, for all practical purposes, quantitatively immaterial. The sweat would seem to be a more important source of loss in animals submitted to much muscular exercise. But, even in their case, it does not seem to be large; while in that of the animals of the farm, fed for the production of meat or milk, it would presumably be much less material.

We now come to the consideration of evidence of quite another kind as to the loss to the manure of the nitrogen of the food, beyond the amount stored up in increase, or removed in milk; namely, that afforded by the results of experiments made to determine the relation of the amount of nitrogen voided in the solid and liquid excretions to that consumed in the food. Most of these have been made with the animals of the farm; indeed, most of them have had for their object the direct determination of the amount of the nitrogen of the food consumed which is recovered in the manure in practical feeding. The chief results may be very briefly summarized as follows:

Boussingault made experiments[3] with a cow, with a horse, and with turtle doves (probably between 1830 and 1840).

In the experiment with a cow the animal was fed on the same food for about a month, and the results relate to the three concluding days of that period. Boussingault observes that the animal did not suffer any material change in weight. Besides the nitrogen removed in the milk, there was an amount not recovered in the excrements which represented a loss of 13.4 per cent of the total nitrogen of the food.

In the experiment with a horse the animal had received the same ration for three months, and did not either gain or lose in weight appreciably. There was here again an amount unaccounted for, representing a loss of 17.2 per cent of the nitrogen of the food.

In the two experiments with turtle doves, one over five and the other over seven days, each of the birds rather lost weight. Their food was millet, and in the one case there was a loss of 35.9, and in the other of 34.1 per cent of the nitrogen in the food. Boussingault thought that

[1] Annales de la Science Agronomique, fifth year, 1888, Tome II, pp. 311–314.

[2] Jour. Physiol., Vol. XI, 1890, p. 497.

[3] Agronomie, Chimie Agricole et Physiologie, 2d ed., 1874, vol. 5, p. 144.

there was undoubtedly a loss of nitrogen, as the amount unrecovered was far too great to be accounted for by errors of analysis.

Experiments were made on the subject at Rothamsted in 1854 with pigs. Individual male animals were experimented upon for periods of three and of ten days. Each animal was kept in a frame, preventing it from turning round, and having a zinc bottom, sloping slightly from each side towards the center, where there was an outlet for the urine to run into a bottle beneath. They were watched night and day, and the voidings carefully collected as soon as passed, which could easily be done, as the animals never passed either feces or urine without getting up, and in so doing rang a bell, and thus attracted the notice of the attendant. The constituents determined were, in the food and feces, dry matter, ash, and nitrogen; and in the urine dry matter, ash, nitrogen, and urea. In preparing samples of feces or of urine for nitrogen determinations a mixture was made of a proportional part of the voiding of each 24 hours, and oxalic acid added. In the case of the feces portions of the acid mixture were taken for the determination of dry matter, and nitrogen determinations were made in the partially dried substance, and calculated up to the fully dried condition. In the case of the urine, portions of the acid mixture were fully dried, and other portions partially dried, and then mixed with about half the weight of fully dried oak dust, in which the nitrogen was determined.

Over a preliminary period, and also over each period of exact experiment, one animal received the highly nitrogenous lentil meal and the other the low-in-nitrogen barley meal. In each case the one receiving lentil meal consumed more than twice as much nitrogen in food and voided more than twice as much in the solid and liquid excrements.

Notwithstanding the great attention paid to the collection, the sampling, and the preparation of the samples of the excrements for nitrogen determinations, as above described, there was in each case a considerable amount of the nitrogen of the food unaccounted for in that estimated in the increase and in that found in the excrements. There was, too, a much greater loss indicated by the results of the direct nitrogen determinations in the urine dried with an excess of oxalic acid than when the nitrogen was calculated from the amount of urea found daily in the fresh urine. As, however, nitrogen determinations (by soda lime and platinum salt) were made by two analysts, whose results agreed very fairly, it may be concluded that the loss was connected with the methods of collection, sampling, and preparation for analysis, rather than with those of the analysis, and it is probable that the same remark applies to the results obtained with the feces. In illustration of the range of loss of nitrogen indicated, it may be stated that, when the nitrogen in the urine was reckoned from the amount of urea, the loss ranged in the four experiments between 20 and 30 per cent of that in the food, and when by direct nitrogen determinations in urine as well as in feces, from under to over 40 per cent. However, in the

case of each food, whether the nitrogen in the urine was determined, or calculated from the urea, there was considerably less loss indicated over the ten-day than over shorter three-day periods, again connecting the error with the collection, sampling, and preparation, rather than with the analysis.

In view of these unsatisfactory results, and of the evidence that much, at any rate, of the loss was probably due to experimental difficulties and errors, the subject was taken up again in 1862. The pigs were kept in frames as before and the voidings were collected in the same way, but they were sampled morning and evening instead of only once in the twenty-four hours, as in 1854. Advantage was also taken of the previous experience in regard to various other points of manipulation. Lastly, the direct nitrogen determinations were made by soda lime as before, but with titration instead of platinum salt.

Two animals were experimented upon, each for a period of ten days, and after an interval of a few weeks for five days more. The food of one consisted of 3 parts bean meal and 1 part bran, and of the other of 3 parts barley meal and 1 part bran.

In the case of the pig having the highly nitrogenous bean meal and bran, the nitrogen balance for the ten days showed a gain of 4.04 per cent when direct nitrogen determinations were made in the urine, and of only 2.32 per cent when the nitrogen in the urine was calculated from the amount of urea. On the other hand, over the five-day period there was a loss indicated of 3.35 per cent with the direct nitrogen determinations in the urine, and of only 1.61 per cent when the nitrogen was calculated from urea. In the latter case, therefore, the amount of nitrogen accounted for was again less with direct determination than by calculation from urea.

In the case of the pig having the low-in-nitrogen barley meal and bran there was over the ten-day period a loss indicated of 7.16 per cent of nitrogen with direct determination, and of only 4.90 per cent when the nitrogen was calculated from the urea. In this case, therefore, there was again less loss of nitrogen by calculation from urea than by direct determination. Lastly, over the five-day period there was with the barley meal and bran a gain of nitrogen indicated of 7.76 per cent with direct determination of nitrogen in the urine, and of 11.02 per cent when calculated from the urea. In both cases, therefore, there was more nitrogen accounted for by calculation from urea than by direct determination.

These results, obtained in 1862, show, therefore, with the beans and bran a slight gain over the ten days and a slight loss over the five days. On the other hand, with the barley and bran there was a comparatively small loss over the ten days and a somewhat greater gain over the five days.

When the fact that there was a much greater variation in the amounts of the daily voidings than in those of the food daily consumed, and also the uncertainty in the estimation of the proper increase of the animals

over short periods, and of the nitrogen in it, are taken into account, these results must be admitted to afford no evidence of any real loss to the manure of the nitrogen of the food beyond that in the increase and in the excrements.

The next results to consider were obtained at Rothamsted in 1861 with sheep. There were four pens, with five sheep in each. Besides the determination of the total dry matter, ash, and nitrogen in the food and in the excrements, one special object was to determine what proportion of the cellulose of the food was digested, and whether more or less was so utilized according to the character of the foods given with it. Accordingly, foods containing a comparatively large amount of cellulose were selected, as under—

Pen 1. Meadow-hay chaff alone, ad libitum.

Pen 2. One pound of ground beans per head per day, and meadow-hay chaff ad libitum.

Pen 3. One pound of ground barley per head per day, and meadow-hay chaff ad libitum.

Pen 4. About 6½ ounces of ground beans and about 3¼ ounces of linseed oil per head per day, and meadow-hay chaff ad libitum.

In pen 4 the object was to give an amount of beans containing the same quantity of nitrogen as the barley of pen 3, and then to make up the deficiency of starch in the smaller quantity of beans compared with that in the barley by oil in the proportion of 1 part of oil for 2½ parts of starch.

With a view to the careful collection, sampling, and analysis of the excrements, the sheep were kept under cover on rafters, through which (but with some loss) the solid and liquid excreta passed on to a sheet-zinc flooring at such an incline that the liquid drained off at once into carboys containing oxalic acid, and the solid matter was removed two or three times daily, and also mixed with oxalic acid.

After a preliminary period of eight weeks the exact feeding experiment was continued for thirty-two weeks more—from January 25 to September 6. Commencing on March 26 and ending on August 9 samples of the excrements were taken at intervals in each case for several consecutive days, namely: 4, 5, 5, 7, 7, 7, 7, 7, 7, and 7 days; and the results here given are the means of the seven seven-day periods. The amounts of nitrogen so indicated to be not recovered in either the increase or in the excreted matters were, in the four pens respectively, 12.5, 25.4, 15.2, and 17.7 per cent of the nitrogen supplied in the food. It is to be observed that the estimated loss is the greatest with the most and the least with the least nitrogen in the food. The question arises whether the greater estimated loss is connected with an underestimate of the nitrogen in the increase of the animals feeding on the more highly nitrogenous food, or with an actually greater loss from decomposition in the case of the more highly nitrogenous excrements.

In 1858 Henneberg[1] made experiments with two oxen, each separately.

[1] Beiträge zur Begründung einer rationellen Futterung der Wiederkaüer, Heft 1, 1860.

The animals were kept on sustenance food only. After a preliminary period of several weeks there were three periods of more exact experiment, the first from February 27 to March 27, the second from March 28 to May 21, and the third from May 22 to July 15, and during three days toward the end of each of these periods the excrements were collected and analyzed. Ox No. 1 gained 6 pounds during the three days of the first period, 1 pound during those of the second, and 11 pounds during those of the third. The percentage of the nitrogen of the food which was not recovered in the excrements was, for the respective three-day periods, 5.7, 28.8, and 15.1, or an average of 16.5. Ox No 2 neither gained nor lost during the first three-day period, lost 3 pounds during the second and 8 pounds during the third; and the analyses of the excrements showed a gain of nitrogen, compared with that in the food, of 9.6 per cent over the first three days, a loss of 24.7 per cent over the second three, and a gain of 6.3 per cent over the third. That is to say, Ox No. 1, with more or less gain over each of the three-day periods, which may, perhaps, be interpreted as retention in the alimentary canal, or bladder, rather than increase in the substance of the body, showed a considerable deficit of nitrogen in the excrements compared with that in the food. Ox No. 2, on the other hand, with loss of weight, which probably only represented more complete evacuation in relation to the food consumed, indicated more of tendency to excess of nitrogen in the excrements compared with that in the food. In experiments in 1860–61, also with two bullocks, Henneberg found, this time over six-day instead of three-day periods, deficits of nitrogen in the excrements corresponding to the following percentages of the amounts supplied in the food: 35, 37, 21, 12, 10. It may be observed that the percentage of loss was, upon the whole, the greater with the larger amounts of nitrogen in the food. Later results of Henneberg will be referred to further on.

In none of the foregoing experiments by Boussingault, at Rothamsted, or by Henneberg, was any litter used, the excrements being collected and analyzed by themselves.

In 1851 we made experiments with oxen, at Woburn Park farm, by the permission of the Duke of Bedford. In the experiment, the results of which are given below, there were five Herefords, each in a separate box, and the experimental period extended over thirty-five days. Liberal fattening food was given, consisting of a cooked mixture of equal parts of ground oil cake, barley, and beans, besides, clover-hay chaff and Swedes. The litter consisted of wheat straw, and an absorbent composed of 2 parts sawdust and 1 part sulphuric acid was used, a small quantity being daily sprinkled over the manure in the boxes just before spreading the fresh litter. At the end of the experiment the whole of the dung was got out, put into a large shed, turned over by men, pulled to pieces by boys, and thoroughly mixed, and in that state it was weighed and several separate 100-pound samples were taken, each being put into a clean cask, in which state the samples were sent to

Rothamsted for analysis. In the preparation for analysis the whole of the 100-pound sample was coarsely ground, then divided into portions, one or more of which was finely ground for analysis, and in the sample so prepared the nitrogen was determined by the soda-lime method. It was so determined separately in samples from two of the 100-pound casks. Deducting the amount of nitrogen in the increase, reckoning it to contain 1.27 per cent, there was a deficiency of nitrogen in the dung compared with that in the food and litter, according to one 100-pound sample of 8.03 and to the other or duplicate one of 10.55 per cent.

Such, then, were the results of the earlier experiments, made by various investigators, to determine whether or not there was any loss of nitrogen in the feeding of animals beyond that stored up in their increase. It will be observed that, with the exception of the turtle-doves experimented upon by Boussingault, all the other results were obtained with the animals of the farm, and in all cases excepting those of the experiments at Rothamsted with pigs and with sheep, and at Woburn with oxen, the animals were assumed to be fed on only sustenance rations, and no allowance was made in the calculations for any increase or loss in their weight. It has been seen that in every case, excepting in the experiment with Henneberg's ox No. 2, and in the experiments at Rothamsted with pigs in 1862, the figures indicate a notable and in some a very considerable loss of nitrogen, which, assuming it to be not explained by storing up of nitrogen in the animal, or deficient evacuation, might be supposed to point to a probable loss by respiration or perspiration, or both.

From a study in much detail of the direct experiments on respiration and perspiration which have been referred to, we ourselves have been disposed to conclude that there was no material exhalation of either free nitrogen or of its compounds. Further, notwithstanding our own early results with pigs, those with sheep, and those at Woburn with oxen, all indicated more or less, and sometimes a considerable loss, the observations made during the conduct of the investigations so fully impressed us with the liability to error, especially on the side of loss, that we have always considered it doubtful whether there was in reality any material loss at all. In the first place there is the uncertainty in the estimation of the changes in the weight of the body, whether to attribute them to increase or loss of its fixed substance, or to excess or deficiency in the evacuations in relation to the food consumed within the period of experiment; and there are, besides, great difficulties to be overcome, both in the complete collection, the proper sampling, and the preparation, without change, of the excreted matters; and there are also special difficulties in the adaptation of analytical methods to secure exact representative results. Indeed, most of the results so far quoted, whether of ourselves or others, must be looked upon as little more than pioneer, though, taken as such, the experience gained has proved to be of essential value in directing attention to the difficul-

ties and sources of error incident to such work, and to the improvement in methods of collection, sampling, preparation, and analysis.

For ourselves, being satisfied that much, if not the whole of the losses that had been indicated was to be explained by the methods of experimenting, and being very fully occupied with other subjects, we decided, after our experiments with pigs in 1862, not to devote the very great amount of time and labor that would be involved in the repetition of the investigation with still further precautions.

In Germany, however, Henneberg and his colleagues (G. Kühn, H. Schultze, and B. Schultze) at Weende, as well as others, continued to work on the subject with the animals of the farm. Henneberg[1] pointed out that the experiments of Bischoff and Voit with dogs in 1859,[2] of Ranke with man in 1860–61,[3] of Voit with pigeons in 1860–'62,[4] and of Pettenkofer and Voit with man,[5] showed almost complete reappearance of the nitrogen of the food in the solid and liquid excretions; and if this were the case with Carnivora and Omnivora there seemed no reason why it should not be so with Herbivora. He further pointed out how small an actual loss or gain in the determined amount of nitrogen in the feces or the urine might make a great difference in the balance; and he admitted that more attention than had hitherto been given to certain points must in future be devoted; as, for instance, to the rinsing and washing of the stalls, and to the determination of the dry matter in the food, feces, and urine, more frequently and uniformly throughout the experimental period.

In the Weende experiments of 1865, and subsequently, more attention was paid to such points, and the periods of exact experiment were longer. There was, accordingly, great improvement in the results. Thus, in a series of eight experiments with oxen, in five with only sustenance or maintenance rations, the result was that in three of them the percentage deficit of nitrogen in the excrements compared with that in the food was 0.4, 2.7, and 2.2, while in the other two there was a gain representing 0.8 and 3.7 per cent. In the three other experiments, fattening food containing about twice as much nitrogen was given, and in these the deficits in the excrements were 12.1, 12, and 17.7 per cent of the nitrogen in the food. Henneberg concluded that, with only sustenance rations the whole of the nitrogen of the food of oxen reappeared in the excrements, and that it was no longer necessary to infer from the results obtained with other animals what would take place with ruminants.

Henneberg also quotes results[6] obtained with cows, by Voit at Munich by G. Kühn and Fleischer at Möckern, and by Fleischer at Hohenheim.

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[1] Neue Beiträge Göttengen I, 373–375. 1872.

[2] Die Gesetze der Ernährung des Fleischfressers, Leipzig, 1860.

[3] Archiv. für anat., phys. und wissenschaftliche Medicin., Leipzig, 1862, p. 311.

[4] Annalen, II Suppl., p. 238, 1862.

[5] Ztschr. Biol. 2, p. 459.

[6] Neue Beiträge, Heft I, p. 383. 1872.

Voit's results, obtained in 1867, showed a deficit of nitrogen in the milk, feces, and urine, representing 1.2 per cent of that in the food. In eight experiments made at Möckern in 1867–68, with cows, six showed, respectively, losses corresponding to 2.9, 11.1, 3.8, 5.6, 16.4, and 7 per cent of the nitrogen in the food, and the other two showed gains corresponding to 1.2 and 4.8 per cent. In the case of the larger losses more nitrogen was consumed in the food, and the animals gained in weight, and presumably stored up nitrogen. At Hohenheim, in 1870, experiments were made by Fleischer with two cows, one of which showed a loss of 0.3, and the other a gain of 0.6 per cent of nitrogen compared with that in the food.

Experiments were also made with sheep by Maercker and E. Schulze at Weende,[1] which confirmed the conclusions drawn from those with oxen and cows as above, as also did others made by Stohmann with goats[2] at the Halle experimental station.

I will conclude the citation of experimental evidence on the point by reference to some of the results obtained by Voit from 1859 to 1863 with dogs.[3] In none of these cases was the period of exact experiment less than six days, while in some it was 12, 14, 20, 23, 49, and even 58 days. In 8 out of the 11 cases there was an excess of nitrogen in the excrements compared with that in the food, representing the following percentages of gain on that in the food: 1, 0.7, 0.4, 0.4, 0.6, 0.3, 0.1, and 0.1, while the deficits represented 0.0, 1.4, and 0.3 per cent.

Since the publication of the various results above quoted, there has been little doubt entertained that, not only in the case of Carnivora and Omnivora, but also in that of Herbivora, and even of ruminants, practically the whole of the nitrogen of the food which does not contribute to animal increase or to milk, reappears in the excrements.

In our estimates of the value of the manure from the consumption of different foods by animals on the farm, so far as the nitrogen was concerned, we many years ago deducted 10 per cent from the amounts consumed in oil cakes and leguminous seeds, which contain high percentages of nitrogen, and 15 per cent from the amounts in the foods which contain lower percentages. These deductions were reckoned to include the amounts of nitrogen actually stored up in the increase of live weight, and also some little loss, if any, but not to cover the larger losses that may take place in the manure after it is voided by the animals. More recently, however, we have estimated the amount actually stored up in the animal, and have assumed the whole of the remainder to be voided in the solid and liquid excretions.

For details on the point, I must refer to our most recent paper bearing

[1] Jour. Landw., 1870 and 1871; Armsby, Manual of Cattle Feeding, 2d ed., 1887, pp. 99, 100.

[2] Ztschr. Biol., 1870, p. 204; Armsby, loc. cit., pp. 100, 101.

[3] Bischoff and Voit, Die Gesetze der Ernährung des Fleischfressers 1860; and Wolff's Die Ernährung d. Landw. Nutzthiere, 1876.

upon the subject entitled "On the valuation of unexhausted manures."[1] The calculations relate to the use of food for the production of fattening increase. It is assumed that, on the average, such increase will contain 8 per cent of nitrogenous substance, corresponding to 1.27 per cent of nitrogen in the increase. According to the calculations it results that of the total nitrogen consumed in foods rich in that substance, such as oil cakes and leguminous seeds, there will generally be less than 5 per cent retained in the fattening increase in live weight. In the case of the cereal grains, on the other hand, which are much less rich in nitrogen, a much larger proportion of the total amount consumed will be retained in the increase, generally perhaps about 10 per cent of it. Of the nitrogen in gramineous straws a still higher proportion will probably be devoted to increase; while roots will on the average lose by feeding perhaps only about 5 or 6 per cent of their nitrogen.

Thus, when fattening increase only is produced, the proportion of the nitrogen of the food which will be retained by the animal, and so lost to the manure, is very small in the case of the richer foods, but more in that of the poorer ones, though even with them it seldom exceeds 10 per cent, except in the case of straws. It may be assumed, however, that when foods are consumed by store animals, whose increase is largely growth, about twice as much of the nitrogen of the food is retained, and so lost to the manure. And when, as is more and more the case with early maturity, the increase comprises a larger proportion of growth than in mere fattening, the amount of the nitrogen of the food which will be lost to the manure will be more than with fattening only, but less than with merely store animals. When, however, food is consumed for the production of milk, a very much greater proportion of its nitrogen will be lost to the manure.

FOOD AND THE EXERCISE OF FORCE.

I now come to the last branch of my subject, namely, the feeding of animals for the exercise of force. With the very limited space left at my disposal, I will commence my historical sketch with a brief account of the views of Liebig as first put forward in 1842 in his work "On organic chemistry in its applications to physiology and pathology." There, is, indeed a special appropriateness in so doing, since there can be no doubt that the course of subsequent inquiry and discussion has been materially influenced by the opinions he then enunciated.

The following quotations from the above-mentioned work will suffice to indicate his more specific views in regard to the connection between food requirements and the exercise of force:

As an immediate effect of the manifestation of mechanical force, we see that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its

[1] Jour. Roy. Agl. Soc. England, Vol. XXI, s. s., Part II, 1885.

power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fiber (just as the acid lost its chemical character by combining with zinc); and all experience proves that this conversion of living muscular fiber into compounds destitute of vitality, is accelerated or retarded according to the amount of force employed to produce motion. Nay, it may safely be affirmed that they are mutually proportional; that a rapid transformation of muscular fiber, or, as it may be called, a rapid change of matter, determines a greater amount of mechanical force; and, conversely, that a greater amount of mechanical motion (of mechanical force expended in motion) determines a more rapid change of matter (pp. 220, 221).

And again—

The amount of azotised food necessary to restore equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed.

The amount of living matter, which in the body loses the condition of life is, in equal temperatures, directly proportional to the mechanical effects produced in a given time.

The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine.

The sum of the mechanical effects produced in two individuals in the same temperature is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera (p. 245).

Such, in fact, were the views in regard to the special exigencies of the system in the exercise of force, which became at once identified with Liebig's name, and continued to be so identified for many years. Thus, Professor Frankland, in his lecture at the Royal Institution, in 1866,[1] on the experiments of Fick and Wislicenus,[2] refers to these views of Liebig as having, up to that time, been pretty generally adopted by text-book writers.

The results of our own feeding experiments, which were commenced some years after the appearance of Liebig's work, being apparently inconsistent with the then current views on some important points, we were led at once to turn attention to the subject of human dietaries; and also to a consideration of the management of the animal body undergoing somewhat excessive labor, as, for instance, the hunting horse, the racer, the cab horse, the foxhound, and also pugilists and runners. The conclusions to which we were led by this study were briefly summarized in a paper published in the Report of the British Association for the Advancement of Science, for 1852, as follows:

* * * That in the cases at least of ordinary exercise of force, the exigencies of the respiratory system keep pace more nearly with the demand for nitrogenous constituents of food than is usually supposed.

And further—

A somewhat concentrated supply of nitrogen does, however, in some cases, seem to be required when the system is overtaxed; as, for instance, when day by day more labor is demanded of the animal body than it is competent, without deterioration, to keep up, and, perhaps, also in the human body, when under excitement or

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[1] Jour. R. Inst., 1866.

[2] Phil. Mag., 1866, 4th series, vol. 21, pp. 485–503.

excessive mental exercise. It must be remembered, however, that it is in butcher's meat, to which is attributed such high flesh-forming capacity, that we have also, in the fat which it contains, a large proportion of respiratory material of the most concentrated kind. It is found, too, that of the dry substance of the egg 40 per cent is pure fat.

A consideration of the habits of those of the laboring classes, who are under rather than over fed, will show that they first have recourse to fat meat, such as pork, rather than to those which are leaner and more nitrogenous, thus, perhaps, indicating that the first instinctive call is for an increase of the respiratory constituents of food. It can not be doubted, however, that the higher classes do consume a larger proportion of the leaner meats, though it is probable, as we have said, that, even with these as well as pork, more fat, possessing a higher respiratory capacity than any other constituent of food, is taken into the system than is generally imagined. Fat and butter, indeed, may be said to have about twice and a half the respiratory capacity of starch, sugar, etc. It should be remembered, too, that the classes which consume most of the leaner meats are also those which consume the most butter, sugar, and, in many cases, alcoholic drinks also.

It is further worthy of remark that wherever labor is expended in the manufacture of staple articles of food, it has generally for its object the concentration of the nonnitrogenous or more peculiarly respiratory constituents. Sugar, butter, and alcoholic drinks are notable instances of this. Cheese, which at first sight might appear an exception, is in reality not so, for those cheeses which bring the highest price are always those which contain the most butter, while butter itself is always dearer than cheese.

In conclusion, it must by no means be understood that we would in any way deprecate the value of even a somewhat liberal amount of nitrogen in food. We believe, however, that on the current views too high a relative importance is attached to it, and that it would conduce to further progress in this most important field of inquiry if the prevailing opinions on the subject were somewhat modified.

It is to be borne in mind that at the time these opinions were put forward, now more than forty years ago, the views expressed were directly contrary to all recognized authority on the subject, and that it is since that date that so much evidence has been accumulated as to the amounts of urea and of carbonic acid given off under varied conditions as to food and exercise. Still, from the facts already at command, it was concluded that the increased demand for food resulting from the exercise of muscular power was specially characterized by the requirement for an enhanced amount of the nonnitrogenous constituents.

Confirmatory evidence was, however, not long wanting. Thus, in 1854, we selected two pigs as nearly as possible of equal weight and character; to one was given, ad libitum, lentil meal (containing about 4 per cent of nitrogen), and to the other, also ad libitum, barley meal (containing less than 2 per cent). Each animal was kept in a frame, with arrangements for collecting the fæces and urine separately as already described. After they had been kept for a certain time on their respective foods, one comparative experiment was conducted for three days and later on another for ten days. The weights of the animals were taken at the beginning and at the end of each experiment, and, besides other particulars, the amounts of nitrogen consumed in the food and of urea voided were determined. The results are summarized in the following table:

TABLE 76.—*Experiments at Rothamsted with pigs, June to August, 1854 (quantities per head per day).*

Periods.	Foods.	Nitrogen in food.	Urea voided.	Urea=nitrogen.
Days.		*Grams.*	*Grams.*	*Grams.*
3	No. 1. Lentil meal	123	134	62.6
3	No. 2. Barley meal	58.9	61.5	28.7
10	No. 1. Lentil meal	120.6	141	65.8
10	No. 2. Barley meal	51.2	52.1	24.3

The result was, then, that with exactly equal conditions as to exercise, both animals being in fact at rest, the amount of urea passed by the one feeding on the highly nitrogenous lentil meal was, in each case, more than twice as great as that voided by the one fed on the barley meal supplying less than half the amount of nitrogen.

It was clear, therefore, that the rule laid down by Liebig, and so long generally adopted by others, did not hold good, namely, that—

The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine, whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera.

Unless, indeed, as has been assumed by some experimenters, there is, with an increase of nitrogenous substance in the food, an increased amount of mechanical force employed in the "involuntary motions" sufficient to account for the increased amount of urea voided.

It was at any rate obvious that, if the amount of urea voided by one animal at rest could be more than twice as great as that voided by a similar animal also at rest, and under otherwise equal conditions, provided only that the food of the one contained more than twice as much nitrogen as that of the other, the amount of urea passed could not be any measure of the amount of muscular power exerted.

The subject was taken up again at Rothamsted in 1862, and accordant results were obtained as follows:

TABLE 77.—*Experiments at Rothamsted with pigs, August to September, 1862 (quantities per head per day).*

Periods.	Foods.	Nitrogen in food.	Urea voided.	Urea=nitrogen.
Days.		*Grams.*	*Grams.*	*Grams.*
10	No. 1. Barley and bran	41.6	43.6	20.4
10	No. 2. Beans and bran	66	89.6	41.8
5	No. 1. Barley and bran	46.2	52.3	24.4
5	No. 2. Beans and bran	82.5	116.6	54.4

Not long after the publication of our views in 1852, and the experiments with pigs in 1854, with the results of which he was acquainted, the late Dr. Edward Smith instituted experiments to determine the amounts of carbonic acid exhaled in respiration, under various conditions as to muscular exercise. His results were published in a paper

presented to the Royal Society on December 16, 1858.[1] He records the quantities of carbonic acid exhaled in grams per minute, and these we have calculated into grams per hour, and so give them below:

	Carbonic acid grams per hour.
During light sleep	19.2
Lying down, scarcely awake	23
Sitting quietly	38.1
Walking 2 miles per hour	70.4
Walking 3 miles per hour	100.4
On treadwheel, ascending 28.65 feet per minute	189.2

There was, therefore, very greatly increased exhalation of carbonic acid with increased muscular exercise.

Dr. E. Smith also conducted experiments on the amounts of urea eliminated under different conditions both as to food and exercise. The investigation was commenced in January, 1860, and continued up to March, 1862, a period of two years and two months. These results were also published in a paper in the Philosophical Transactions of the Royal Society.[2] The general result was, that there was great variation in the amount of urea passed when there was concurrent variation in the amount of nitrogenous substance in the food; but, on the other hand, comparatively little variation in the amount of urea voided, with great variation in the amount of labor performed.

Thus, then, Dr. Smith's results, both those showing the amounts of carbonic acid exhaled and those relating to the amounts of urea voided, fully confirmed the view that with muscular exertion there was a marked increase in the demand for the nonnitrogenous and but little, if any, in that for the nitrogenous constituents of food.

Experiments made by Bischoff and Voit in 1858 and 1859[3] with a dog, either submitted to hunger or fed from time to time on foods containing very different amounts of nitrogenous substance, showed very variable amounts of urea voided, although the animal was kept under equal conditions as to exercise. Still, on the publication of their results in 1860, the authors assumed that although there had been no greater exercise of force manifested in the form of external work, yet when the amount of nitrogenous substance in the food was greater, and the amount of urea voided correspondingly greater, there must have been a corresponding increase in the force exercised in the conduct of the actions within the body in connection with the disposition of the increased amount of nitrogenous substance consumed; so that, after all, the amount of urea eliminated was a measure of the exercise of force, though not in the voluntary exercise of muscular power.

Being in Germany in the summer of 1860, and visiting Munich, I had some conversation with Professor Voit on the subject of their

[1] Phil. Trans., 1859, p. 681.

[2] Ibid., 1861, p. 747.

[3] Die Gesetze der Ernährung des Fleischfressers, 1860.

results and conclusions. Referring to our own results obtained in 1854 with pigs, I pointed out that they were entirely consistent with those which he and Professor Bischoff had obtained with a dog, but that we had drawn very different conclusions from them. He left the impression, however, that he considered that I was entirely in error.

Later in the same year, however, Voit published[1] the results of further experiments with a dog. In these he submitted the animal to alternate rest and labor, sometimes fasting, sometimes with a moderate and sometimes with a liberal supply of nitrogenous substance in food. The labor consisted of working in a kind of treadwheel. He found that the amount of urea eliminated was not in proportion to the exercise of force, but was very nearly proportional to the amount of nitrogenous substance consumed. He considered that by such a result the views which he and others had maintained as to the connection between the exercise of force, the degradation of nitrogenous substance within the body, and the elimination of urea, were completely overturned.

In 1862 Pettenkofer and Voit published a paper[2] giving the results of experiments with a dog, made in 1861 and 1862, in which the food consumed, the amount of urea voided, and the quantity of carbonic acid given off by the lungs and skin were determined, the latter in Pettenkofer's respiration apparatus. These experiments were more or less preliminary, and during their conduct the animal was not submitted to any labor.

Subsequently Pettenkofer and Voit made experiments, in which they determined both the nitrogen in the urine and the carbonic acid evolved, not only in rest but in work, sometimes fasting and sometimes with food. Their results were published in 1866, in the Zeitschrift für Biologie. The following table gives average results for twenty-four hours in experiments made with a man, with the aid of Pettenkofer's respiration apparatus:

TABLE 78.—*Experiments with a man by Pettenkofer and Voit.*

	Nitrogen in urine.	Carbonic acid exhaled.
In hunger:	*Grams.*	*Grams.*
In rest	12.39	716
In work	12.26	1,187
With moderate diet:		
In rest	17.01	928
In work	17.33	1,209

Thus, not only was there no increased transformation of nitrogenous substance by the exercise of force, but there was a very greatly increased exhalation of carbonic acid. It is evident, therefore, that in the exercise of force the exigency of the system is specially characterized by an

[1] Untersuchungen über den Einfluss des Kochsalzes, Kaffees und der Muskelbewegungen auf den Stoffwechsel, 1860.

[2] Ann. Chem. Pharm., II. Supplement band, I. Heft., p. 52.

increased demand in the food for, so to speak, respiratory material. The results of Pettenkofer and Voit are indeed of great importance, but in Germany they are even looked upon as being the first to establish the correct view on the subject.

Abundant further confirmation of the now generally accepted view is available, and it will be of interest to give some illustrations.

In 1866 results were published[1] as to the amount of nitrogen excreted before, during, and after, ascending the Faulhorn, by Professors Fick and Wislicenus, in August, 1865. The experimenters took an ordinary meal at midday on the 29th, but then only starch, fat, and sugar, until after the ascent, which commenced early the next morning. The following is a summary of the results so far as they relate to the point under consideration:

TABLE 79.—*Nitrogen excreted by men with and without exercise.*

	Urea.	Nitrogen in urea.	Total nitrogen.	Nitrogen excreted per hour (average).
Fick.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
Night before ascent	12.4820	5.8249	6.9153	0.63
During ascent	7.0330	3.2681	3.3130	.41
After ascent	5.1718	2.4151	2.4293	.40
Night after ascent	....	....	4.8167	.45
Wislicenus.				
Night before ascent	11.7614	5.4887	6.6841	.61
During ascent	6.6973	3.1254	3.1336	.39
After ascent	5.1020	2.3809	2.4165	.40
Night after ascent	....	....	5.3462	.51

The record of the actual quantities is sufficient to show that much less nitrogen was excreted by both experimenters during, and after, than before the ascent. But the calculated amounts of nitrogen excreted per hour during each of the periods, as given in the last column of the table, bring the main result more clearly to view. It is seen that, on the average, only about two-thirds as much nitrogen was excreted per hour during and after the ascent, as prior to it, when there would be more or less residue in the system from the last albuminous meal.

The above results of Fick and Wislicenus were brought forward by Professor Frankland in a lecture which he gave at the Royal Institution in 1866 "On the source of muscular power." He subsequently himself made numerous calorimetrical determinations of the energy evolved by the combustion of muscle, urea, and various foods, or constituents of foods, the results of which were published in a paper "On the origin of muscular power."[2] Stated in a few words, his main conclusion was, that the transformation of muscular tissue alone can not account for more than a small fraction of the muscular power developed by animals.

[1] Phil. Mag., 1866, 4th series, vol. 31, pp. 485–503.

[2] Ibid., vol. 32, pp. 182–199.

Dr. Oskar Kellner, who was one of Prof. Emil von Wolff's associates in numerous investigations with animals at Hohenheim, made experiments there with a horse,[1] from June 15 to August 10, 1878. The daily food of the animal consisted of 5 kilograms meadow hay, 6 kilograms oats, and 1.5 kilograms wheat-straw chaff. The horse was made to go different distances and to draw different weights, the draft being measured by a horse dynamometer.

The following is a summary of some of the conditions and results of the experiments:

TABLE 80.—*Experiments with a horse by Kellner.*

Experiments.	Number of days.	Live weight.	Per day. Work done.	Per day. Urine voided.	Per day. Nitrogen in urine.
		Kilos.	*Kilometers.*	*C. C.*	*Grams.*
No. 1	6	534.1	475,000	6,730	99
No. 2	10	529.5	950,000	6,473	109.3
No. 3	14	522.5	1,425,000	8,106	116.8
No. 4	12	508.8	950,000	8,686	110.2
No. 5	14	518.0	475,000	9,548	98.3

In reference to these results, which certainly do show an increased excretion of nitrogen with increased work during the second, third, and fourth periods, as compared with the first and fifth, Kellner considers that they are inconsistent with the conclusions of Pettenkofer and Voit, and others, which connect muscular action more exclusively with the oxidation of nonnitrogenous matters, and that those views require to be modified. At the same time, admitting that the transformation of organic substance is to be considered the source of muscular power, he considers that, in the first line, comes the oxidation of nonnitrogenous matters—carbohydrates and fat; in the second the transformation of circulation—albumin; and lastly, that of the organized albumin, which is only attacked if other matters are not available in sufficient quantity. Further, he considers it is evident that the increased albumin transformation was not sufficient to cover the requirements of the increased work, and that this increased transformation and the loss of body weight show the insufficiency of the food, and of the available fat of the body.

The table, in fact, does show that, with increased work done, there was decline in body weight; and, assuming with Kellner, that there was a deficiency of food and of body fat, it seems probable that the increased elimination of nitrogen in the urine is the necessary coincident of real dilapidation of the system. It is obvious that, so far as this is the case, the results are not discordant with our own early view on the subject, since fully established by others. These results of Kellner's are, indeed, a confirmation of the view we put forward in 1852, that—

[1] Landw. Jahrb., Vol. III, part 5, 1879, pp. 701–712.

A somewhat concentrated supply of nitrogen does, however, in some cases, seem to be required when the system is overtaxed; as for instance when, day by day, more labor is demanded of the animal body than it is competent without deterioration to keep up.

In 1885 Grandeau and Leclerc published the results of an experiment with a horse,[1] of which the following is a summary:

Nitrogen in urine for 100 in food.

	Per cent.
Rest	62.4
Walking	67.7
Trotting	64.9
Drawing:	
Walking	60.9
Trotting	59.2

The results show, over the first three experiments, some but not great variation in the amount of nitrogen eliminated with exercise, but the amounts are less in the fourth and fifth experiments and almost identical with walking and trotting. Upon the whole there is no evidence of direct connection between the amount of exercise of force and that of nitrogen eliminated in the urine.

The next results give very definite evidence as to the connection between the amount of carbonic acid exhaled and that of the force exercised. The experiments were made with a horse by Zuntz and Lehmann in 1887 and 1888,[2] and the average results were as follows:

Carbonic acid exhaled per hour (average).

	With mask.	With tracheal canula.
	Cubic feet.	*Cubic feet.*
Rest	3.327	2.861
Work	19.643	17.291
After work	4.662	3.899

Thus, then, there was about six times as much carbonic acid exhaled per hour during work as in rest; and when the work had ceased there was very great reduction in the amount of carbonic acid given off.

The following results by Prof. F. Smith, of Aldershot, were published by him in 1890.[3]

TABLE 81.—*Experiments with horses by Smith.*

	CO_2 expired per hour.		
	Pony (work trotting).	Horse (work galloping).	Horse (work galloping).
	Cubic feet.	*Cubic feet.*	*Cubic feet.*
Rest	0.7648	....	....
Work	2.3954	20.6265	12.4353
After work	.4631	1.3133	1.1693

[1] Ann. Sci. Agron., 1885, 2me Année Tome I, p. 326.

[2] Landw. Jahrb., Vol. 18, 1889, p. 1.

[3] Jour. Physiol., Vol. XI, No. 1.

As in the experiments of Zuntz and Lehmann, quoted above, the great increase in the amount of carbonic acid exhaled during work, and the great reduction in the amount after the cessation of the work, are here again clearly illustrated.

The next table summarizes numerous results by Prof. F. Smith with horses at different paces (loc. cit., p. 77).

TABLE 82.—*Experiments with horses by Smith.*

	CO_2 expired per hour.	
	Series A.	Series B.
	Cubic feet.	*Cubic feet.*
Rest	1.0282	1.2346
Walking	1.0972	1.0586
Trotting	2.9482	4.8309
Cantering	4.9159	5.0080
Galloping	14.9725	....

These strictly gradationary results, with one slight exception, illustrate more clearly still the greater exhalation of carbonic acid the greater the exercise of force.

Turning from the foregoing evidence of direct experiment, indicating the characteristic food requirements for the exercise of force, it will be of interest to give a few examples of the rations adopted as the joint result of direct experiment and large experience.

At page 309 the results of some experiments by Grandeau and Leclerc with a horse were given, showing no direct connection between the amount of force exercised and that of nitrogen eliminated in the urine. Their experiments were made at the establishment of the "Petits Voitures" Company in Paris, and the following table gives the standard daily ration of the horses at the time, the experimentally determined maintenance ration, and that finally adopted for work.

TABLE 83.—*Rations used in experiments with horses by Grandeau and Leclerc.*

Ration.	Beans.	Oats.	Maize.	Maize cake.	Hay.	Straw.	Total food.	Total dry substance.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Previous	1.54	7.23	5.34	1.06	3.84	2.09	21.10	18.14
Maintenance No. 1	.93	4.34	3.20	.63	2.30	1.24	12.64	10.87
Maintenance No. 2	.84	3.91	2.88	.57	2.07	1.12	11.39	9.79
For work	1.39	6.51	4.81	.95	3.46	1.87	18.99	16.33

It seems that the system of the establishment was to work the horses on alternate days; and to give less hay, straw, and maize, but more oats and beans, though less total food, on the days of work. The figures in the top line representing the "previous" ration are, in each case, the means of the two days' ration. The "maintenance ration No. 1" was fixed at three-fifths of the "previous" ration; but as the animals gained in weight, the "maintenance ration, No. 2," which was one-tenth less than No. 1, was subsequently adopted. Even then the horses rather

gained in weight. Finally, as it was considered that the standard or "previous" ration was too high, the ration for work as given in the bottom line of the table, which is one-and-a-half times as much as the "maintenance ration No. 1," and about one-tenth less than the "previous" ration, was adopted. It is, however, said that, under the new régime, the horses were somewhat underfed; but whether the reduced ration is still maintained I am not aware. It will be observed that the proportion of the highly nitrogenous leguminous corn (beans), was very small compared with that of the gramineous grains. Still, as will be seen presently, the proportion was very considerably higher than in the case of the omnibus horses of Paris.

The following table gives the average daily ration of the horses of the General Omnibus Company of Paris for each of the six years, 1879, 1880, 1884, 1885, 1886, and 1887. The average number of horses was about 13,000, and their average weight was from 1,200 to 1,240 pounds, while so far as the evidence goes, those of the "Petits Voitures" Company weighed little more than two-thirds as much; and certainly the former are much heavier than, as a rule, are the omnibus or tramway horses of our own country. The figures are calculated from the results given in the annual reports of M. E. Lavalard,[1] the general secretary of the company, the quantities being converted from kilograms into their equivalent in English pounds.

TABLE 84.—*Rations for horses used by General Omnibus Company of Paris.*

Year.	Beans.	Oats.	Maize.	Hay.	Straw.	Bran, etc.	Total food.	Total dry substance.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1879	1.36	10.04	6.85	9.14	10.45	....	37.84	32.17
1880	1.41	8.84	8.25	7.80	11.10	....	37.40	31.83
1884	1.44	8.67	8.53	8.44	8.71	0.91	36.70	31.29
1885	.89	6.21	11.30	8.50	8.36	.84	36.10	30.84
1886	.10	5.51	12.96	8.64	7.32	.54	35.07	30.03
1887	.01	8.08	10.77	8.65	8.21	....	35.72	30.52

It will be seen that the actual amount of dry substance supplied per head per day is nearly twice as much as in the case of the "Petits Voitures" horses; that is, much more in proportion to a given live weight. It will be further seen that the proportion of beans to cereal grains is much less than in the case of the "Petit Voitures" horses, and was reduced to a very small quantity in the later years. In fact, the corn given consisted almost exclusively of oats and maize, that of the oats being reduced, but that of the maize in a greater degree increased in the later years, coincidently with the reduction in the amount of beans. On the occasion of a visit to M. Lavalard in 1887, I suggested that the supply of the highly nitrogenous leguminous seeds might be mainly, if not exclusively, reserved for old or over-

[1] Rapports sur les opérations du service de la Cavalerie et des Fourrages.

worked horses; and he subsequently informed me that he had found their use in such cases advantageous.

In his annual report for 1886, published in 1887, M. Lavalard gives, on the authority of Dr. Fleming, principal veterinary surgeon of the army, a list of the average daily rations of horses of tramway companies in the United Kingdom; which are quoted in the following table from Dr. Fleming's book.[1] We have also calculated the quantity of dry substance in the total food according to the supposed average composition of each.

TABLE 85.—*Average rations of horses in United Kingdom, after Fleming.*

<table>
<tr><th>Company.</th><th>Beans or peas.</th><th>Oats.</th><th>Maize.</th><th>Hay.</th><th>Straw.</th><th>Bran.</th><th>Total food.</th><th>Total dry substance.</th></tr>
<tr><td></td><td>Pounds.</td><td>Pounds.</td><td>Pounds.</td><td>Pounds.</td><td>Pounds.</td><td>Pounds.</td><td>Pounds.</td><td>Pounds.</td></tr>
<tr><td>North Metropolitan</td><td>2</td><td>3</td><td>13</td><td>7</td><td>3</td><td>..........</td><td>28</td><td>24.09</td></tr>
<tr><td>London</td><td>3</td><td>3</td><td>7</td><td>12</td><td>1</td><td>..........</td><td>26</td><td>22.20</td></tr>
<tr><td>London street</td><td>1</td><td>3</td><td>12</td><td>11</td><td>..........</td><td>1</td><td>28</td><td>24.09</td></tr>
<tr><td>South London</td><td>1</td><td>7</td><td>7</td><td>11</td><td>3</td><td>..........</td><td>29</td><td>24.76</td></tr>
<tr><td>Birmingham</td><td>4</td><td>10</td><td>6</td><td colspan="2">12</td><td>..........</td><td>32</td><td>27.30</td></tr>
<tr><td>Liverpool</td><td>4</td><td>..........</td><td>12</td><td>14</td><td>..........</td><td>1</td><td>31</td><td>26.58</td></tr>
<tr><td>Manchester</td><td colspan="3">15</td><td>15</td><td>..........</td><td>..........</td><td>30</td><td>25.55</td></tr>
<tr><td>Glasgow</td><td>..........</td><td>6</td><td>11</td><td>8½</td><td>1</td><td>½</td><td>27</td><td>23.24</td></tr>
<tr><td>Edinburg</td><td>4</td><td>8</td><td>4</td><td>14</td><td>(a)</td><td>..........</td><td>32</td><td>(25.56)</td></tr>
<tr><td>Dublin</td><td>..........</td><td>3</td><td>14</td><td>12</td><td>..........</td><td>½</td><td>29½</td><td>25.41</td></tr>
</table>

a Also 2 pounds of "marshlam."

There can be little doubt that the average weight of tramway horses in the United Kingdom is much less than that of the omnibus horses of Paris, and it will be seen that the quantity of total food, or total dry matter of food, given per head per day, is also considerably less, though it is much greater than in the case of the smaller "Petits Voitures" horses of Paris.

The details show that, at any rate at that date, the tramway horses in the United Kingdom received much more of the highly nitrogenous leguminous corn—beans or peas—than the Paris horses, and, according to the figures, this was especially the case in Birmingham, Liverpool, and Edinburg. Oats and maize nevertheless contributed most of the corn; the maize generally predominating, while at the present time it will doubtless do so in a greater degree.

Reviewing the whole of the results which have been adduced illustrating the characteristic food requirements for the exercise of force, it may in the first place be observed that the evidence is cumulative and decisive, that, with normal feeding and with only moderate exercise, there is practically no increased demand for the nitrogenous constituents of food; while there is, on the other hand, an increased demand for the more specially respiratory constituents, largely in proportion to the amount of force exercised. If, however, the labor is abnormally heavy—that is, if it be pushed to the point of dilapidation, as indicated

[1] The Practical Horse Keeper, by C. Fleming, LL. D., p. 88.

by loss of weight—there will, in that case, be an increased elimination of nitrogen in the urine, resulting from the degradation of nitrogenous substance, and accordingly an increased demand for the nitrogenous constituents of food.

Lastly, it is of interest to observe that where the subject has been the most carefully investigated the rations adopted for horses include scarcely any of the more highly nitrogenous foods, such as leguminous seeds, but, in addition to hay and straw chaff, consist almost exclusively of the comparatively low in nitrogen cereal grains; and would, therefore, be characterized by containing a comparatively large amount of digestible nonnitrogenous constituents in proportion to the digestible nitrogenous substance of the food. It has, however, been found that in the case of old or overworked animals it is advantageous to supply a somewhat larger amount of the highly nitrogenous leguminous seeds. In fact, as we put it in 1852—

A somewhat concentrated supply of nitrogen does, however, in some cases seem to be required when the system is overtaxed: as, for instance, when day by day more labor is demanded of the animal body than it is competent without deterioration to keep up.

SUMMARY ON THE FEEDING OF ANIMALS.

In introducing the subject of the feeding of the animals of the farm, attention was first called to the amount of the constituents of the crops grown in an ordinary four-course rotation, which would, if the grain only were at once sold, be retained upon the farm for further use; in fact, for the production of meat, milk, and manure, and for the exercise of force. There will, as a rule, be a greater or less amount of grass in admixture with the arable land of the farm; and, according to its amount and other circumstances, there will, of course, be more or less stock food available in addition to that produced on the arable land. So far as manure is concerned, in some cases the grass land, and in others the arable, will be the gainer by the admixture of the two, accordingly as the one or the other receives back more or less than the amount derived from the consumption of its own produce. Then, again, the influence of the growing modern practice of selling more than the grain, and of importing cattle food and manure from external sources has to be taken into account. Nevertheless, the illustration derived from a consideration of the proportion of the constituents of the crops grown under a particular system of rotation which will probably be available for feeding purposes is not without interest and utility.

The facts and arguments which have been adduced may be very briefly summarized as follows: It has been shown that the amount of food consumed, both for a given live weight of animal within a given time, and for the production of a given amount of increase, is, as our current food stuffs go, measurable more by the amounts they contain of digestible and available nonnitrogenous constituents than by the amounts of the digestible and available nitrogenous constituents they supply.

That this should be the case, so far as the consumption for a given live weight within a given time is concerned, seems consistent enough when the prominence of the respiratory function in the maintenance of the body and the large requirement for nonnitrogenous constituents of food to meet the expenditure by respiration are borne in mind. But, at first sight, it seems less intelligible that the quantities consumed to produce a given amount of increase in live weight should also be much more dependent on the supplies of the nonnitrogenous than on those of the nitrogenous constituents of food.

It has been shown, however, that store animals may contain as much, or even more, of the nonnitrogenous substance—fat—than of nitrogenous substance, while the bodies of fattened animals may contain two, three, four, or more times as much dry fat as dry nitrogenous matter. Obviously, therefore, the proportion of fat to nitrogenous substance in the increase in live weight of the fattening animal must be much higher than in the entire bodies of the animals.

Then, it has been further shown that the nonnitrogenous substance of the increase, the fat, is at any rate in great part, if not entirely, derived from the nonnitrogenous constituents of the food. Of the nitrogenous compounds of food, on the other hand, only a small proportion of the whole consumed is finally stored up in the increase of the animal. In other words, a very large amount of nitrogen passes through the body beyond that which is finally retained in the increase, and so remains for manure.

It is, therefore, only what should be expected, that the amount of food consumed to produce a given amount of increase in live weight, as well as that required for the sustenance of a given live weight for a given time, should, provided the food be not abnormally deficient in nitrogenous substance, be characteristically dependent on its supplies of digestible and available nonnitrogenous constituents.

Again, it has been shown that in the exercise of force there is a greatly increased expenditure of the nonnitrogenous constituents of food, but little, if any, of the nitrogenous.

Thus, then, for maintenance, for increase, and for the exercise of force, the exigencies of the system are characterized more by the demand for the digestible nonnitrogenous or more especially respiratory and fat-forming constituents than by that for the nitrogenous or more especially flesh-forming ones.

In our paper "On the composition of oxen, sheep, and pigs, and of their increase while fattening," published in 1860,[1] we concluded that if fattening oxen were liberally fed upon good food, composed of a moderate proportion of cake or corn, some hay or straw chaff, with roots or other succulent food; if sheep were fattened under somewhat similar conditions, but with a less proportion of hay or straw; and if pigs were liberally fed chiefly on cereal grain, the increase would, with

[1] Jour. Roy. Agl. Soc. England, 1st series, Vol. XXI, 1860, p. 433.

as much as 5 or 6 parts of total nonnitrogenous to 1 of nitrogenous compounds in the dry substance of such fattening food, probably be very fat. Further, that in the earlier stages of growth and feeding, a lower proportion of total nonnitrogenous constituents—that is, a higher proportion of the nitrogenous compounds—is desirable; indeed, that it is frequently the most profitable, having regard both to the rapidity of fattening and to the value of the manure, for the farmer to employ, even up to the end of the feeding process, a somewhat higher proportion of nitrogenous constituents in his stock foods than is necessary to yield the maximum proportion of increase in live weight for a given amount of dry substance of food consumed. But that when the mixed fattening food contains less than about 5 parts of nonnitrogenous to 1 of nitrogenous compounds, the proportion of increase in live weight for a given amount of the dry substance of the food will not increase with the increased proportion of nitrogenous compounds consumed: while so far as these are in excess, the proportion of carcass in the live weight will probably be somewhat less, and the carcasses themselves will be somewhat more bony and fleshy, with less fat.

We at the same time pointed out, however, that the comparative values of food stuffs, even as such, could not be unconditionally determined by the percentage of the total nitrogenous and the total nonnitrogenous constituents; that it was necessary to examine more closely into the nature and condition of the proximate compounds of food stuffs to distinguish those which are digestible and assimilable from those which are not so, to determine the relative values of the comparable or mutually replaceable portions, and finally, to fix our standards of comparative value with more of reference to direct experimental evidence on the point and to existing knowledge of the composition of the animal bodies than had hitherto been usual, or even possible.

Since then an immense amount of labor has been expended in the determination of the digestibility of the individual constituents of various food stuffs, and the results so far obtained form a valuable contribution to our information on the subject. There is, however, wide variation in the composition of different samples of nominally the same description of food. Then, the determinations of the amounts of the various constituents remaining undigested have generally been made with animals fed on limited supplies of food for maintenance only, and the experiments have frequently been made with the individual foods given separately. Great care and reservation are therefore necessary in the application of the results to actual practice. Thus, in the liberal feeding of animals for the production of increase it is generally economical to give within limits an excess of food, if a maximum result is to be obtained for a given live weight of the animal within a given time; and, in the case of animals liberally fed for the exercise of force, there will also generally be an excess of food given. It is obvious that, under the conditions of actual practice here assumed, greater proportions of the

various constituents consumed will remain undigested than would be indicated by the figures representing indigestibility obtained under the usual conditions of experimenting on the point above referred to. Then there is the important consideration that conclusive evidence is still wanting as to the exact rôle in the system of some prominent constituents of food stuffs. For example, there is yet much uncertainty in regard to the position of the various amides, which enter so largely into the composition of feeding roots and hays; in fact, of all succulent and unripened products. Indeed, in the calculation of "nutritive ratios," the amides have sometimes been classed with the albuminoids, and sometimes in large proportions with the nonnitrogenous constituents. We have from time to time had the results of our numerous feeding experiments with both sheep and pigs calculated according to the published tables of digestibility. But the so-calculated "ratio" varied so considerably for different rations within the range of good practice that it would be misleading to attempt to give anything like a summary of the results and general conclusions therefrom, without full discussion, which would be neither appropriate nor possible on the present occasion.

In conclusion, as our current fattening food stuffs go, assuming of course that they are not abnormally low in the nitrogenous constituents, they are, as foods, more valuable in proportion to their richness in digestible and available nonnitrogenous than to that of their nitrogenous constituents. As, however, the manure of the animals of the farm is valuable largely in proportion to the nitrogen it contains, there is, so far, an advantage in giving a food somewhat rich in nitrogen provided it is in other respects a good one, and weight for weight not much more costly.

EXPERIMENTS AT ROTHAMSTED, ON THE FEEDING OF ANIMALS.

Results with 30 lots of pigs, 1850–'54; foods containing various proportions of nitrogenous and non-nitrogenous constituents.

One food always *ad libitum*; hence the animals fixed their own consumption.

DIAGRAM I.—SHOWING THE PROPORTIONS CONSUMED PER 100 LBS. LIVE-WEIGHT PER WEEK.

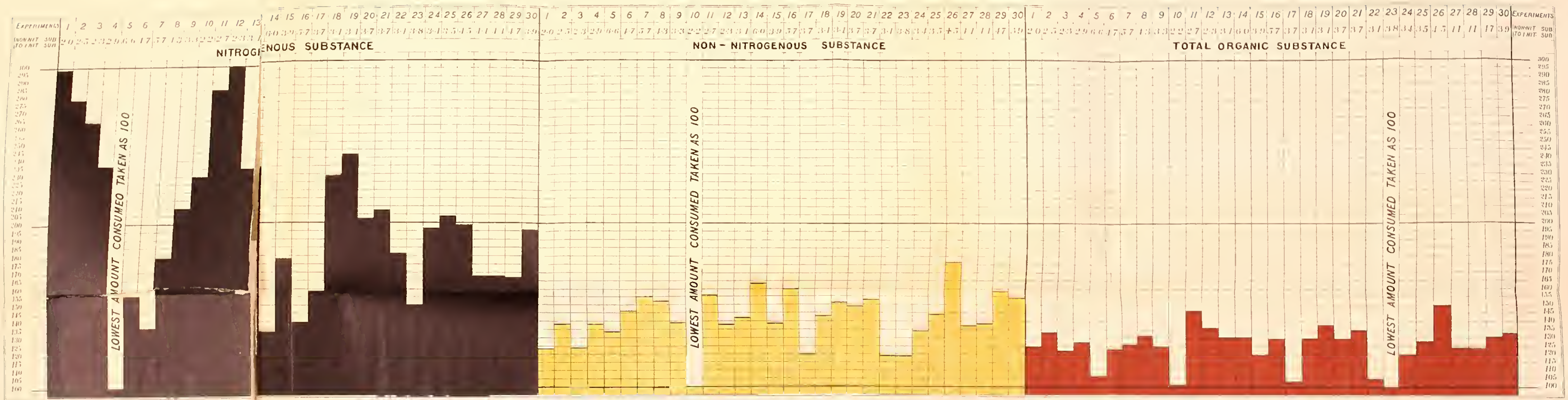

DIAGRAM II.—SHOWING THE PROPORTIONS CONSUMED TO PRODUCE 100 LBS. INCREASE IN LIVE-WEIGHT.